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Sumar

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Effects of sizing and yarn structural properties on the physical properties of combed and carded cotton ring yarns

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REZUMAT – ABSTRACT

Efectul încleierii și proprietăților structurale ale firelor asupra proprietăților fizice ale firelor din bumbac cardate și pieptănate filate cu inele

Firele de urzeală, pregătite sub formă de suluri de urzeală, sunt expuse diferitelor forțe ale mașinii de țesut. Firele de urzeală sunt curbate pe traversa de tensionare, supuse frecării în lamele și cocleți. Acestea sunt, de asemenea, expuse la frecarea și impactul spatei și, prin urmare, abraziunii. Firele sunt încleiate pentru a crește rezistența lor la aceste efecte. Agenții de încleiere, prin procesul de încleiere, permit firelor de urzeală să fie țesute. Pe de altă parte, finețea firelor și tipul de fir (pieptănat sau cardat) sunt proprietățile structurale semnificative care determină proprietățile fizice ale firelor.

Principalul obiectiv al acestui studiu este de a investiga efectele parametrilor structurali (finețea firului și tipul de fir) și a încleierii asupra proprietăților fizice (rezistența la rupere, alungirea la rupere, pilozitatea, coeficientul de frecare) ale firelor de bumbac 100% cardate și pieptănate filate cu inele, încleiate cu patru agenți de încleiere diferiți, care nu au fost studiați în referințe. Se observă că procesul de încleiere determină o scădere a pilozității cu până la 99% și a coeficienților de frecare ai firelor cardate și pieptănate, în timp ce crește rezistența la rupere a firelor cardate și pieptănate. De asemenea, firele pieptănate au avut proprietăți mai bune de rezistență la rupere și la frecare decât firele cardate.

Cuvinte-cheie: fir cardat, fir pieptănat, fir filat cu inele, încleiere, rezistență la rupere, alungire la rupere, pilozitate, coeficient de frecare

Effects of sizing and yarn structural properties on the physical properties of combed and carded cotton ring yarns

Warp yarns, prepared as warp beam, are exposed to various forces at weaving loom. Warp yarns are bended on the back rest, subjected to friction from drop wires and healds. They are also exposed to friction and impact at reed and thereby abraded. Yarns are sized in order to increase their resistance to these effects. Sizing agents ensure that warp yarns can be weaved with sizing process. On the other hand, yarn count and yarn type (combed or carded yarn) are the significant yarn structural properties that determine and so affect the physical properties of yarn. The main reason and objective this study is to investigate the effects of yarn structural parameters (yarn count and yarn type) and sizing on the physical properties (breaking strength, elongation at break, hairiness, friction coefficient) of 100% cotton carded and combed ring yarns, sized with four different sizing agents, which were not studied in the references. It is observed that sizing process cause to decrease in the hairiness up to 99% and in friction coefficients of combed and carded yarns whereas to increase in the breaking strengths of combed and carded yarns. And also, the combed yarns had better tensile and frictional properties than carded yarns.

Keywords: carded yarn, combed yarn, ring yarn, sizing, breaking strength, elongation at break, hairiness, coefficient of friction

INTRODUCTION

The weaving process is based on various factors and on interaction of these factors, including yarn structural parameters, the sizing operation and the sizing agents. Yarn has a complex structure and is defined by many physical properties. It has been considered that the tensile properties of the yarn, which are strength and elongation, are always the prime factors which affect the performance of warp yarns during weaving and weaving preparation. Nevertheless, in recent years it has been realized that the hairiness and friction properties of yarns have equal influence on the performance of the loom and warping machine. The warp yarns may break during the process of weaving and warping due to the complicated mechanical actions consisting of cyclic or noncyclical extension, friction and bending. In order to prevent warp yarns from excessive breakage during weaving and warping, the threads should be sized to be gained better friction properties and to be improved their strength. Sizing is the important weaving preparation operation in terms of decreasing the number of breaks both in weaving and warping processes of cotton yarns. So it increases efficiency of loom and warping machine and also woven fabric quality.

Therefore researchers investigated the effects of sizing on yarn physical properties: Schwarz, Kovacevic and Dimitrovski analysed areas of elastic, viscoelastic and plastic deformations of ring and rotor-spun yarns before and after sizing with a PVA sizing agent, using the same recipe, but with two different size concentrations, 7.5% and 5.0% [1]. By sizing, they achieved major improvements in mechanical properties of ring-spun yarns, contrary to the minor improvements in mechanical properties of rotor-spun yarns, due to their structures.

Behera, B.K., Pakhira, A. applied various size materials (polyvinyl alcohol, polyester resin, polyacrylamide) to both flat (with linear density per filament of 1.04, 2.08 and 4.41 den, respectively) and textured (0.50, 1.41 and 2.22 den per filament, respectively) zero-twisted PET multifilament yams [2]. They observed that breaking strength of yarns increased with sizing whereas breaking extension (%) of yarns decreased with sizing. While difference between yarns sized with polyester resin and unseized yams were significant (at 1% level) for all yarns, difference between yarns sized with polyvinyl alcohol and unseized yams were significant for 4.41 den flat, 1.41 and 2.22 den textured yarns.

Maatoug, S., Ladhari, N. and Sakli, F. investigated the physical properties of Nm 12.2 cotton warp yarns sized at high pressure squeezing with maize starch, polyvinyl alcohol and carboxymethyl cellulose [3]. They observed that the breaking strengths of all sized yarns increased when compared with unsized yarns, while their breaking extensions were reduced. And also, hairiness decreased with sizing.

Behera, B.K. and Joshi, V.K. evaluated relative weaving potential of Dref yarns, with core of polyester filament and cotton sheath and with core of cotton yarn and cotton sheath, which were sized modified maize starch and with acrylic size [4]. They observed that increasing size add-on increased the weaving performance of Dref yarns and the optimum size add-on was approximately 15%.

Jaouachi, B., Ben Hassen, M. and Saklı, F. sized the wet pneumatic-spliced denim yarns according to two different recipes [5]. They found that sizing encouraged the breaking strength of spliced yarns. In other study, Jaouachi, B., Ben Hassen, M. and Saklı, F. compared the mechanical behaviours (breaking strength, elongation at break) of both parent and wet pneumatic spliced cotton denim yarns before and after sizing by natural and synthetic sizes [6]. They found that the synthetic size gave better performance to wet spliced cotton yarns.

Carded cotton yarn, that is carded but not combed, contains a wider range of fibre lengths as a result of this, it is not as uniform and as strong as combed yarns. And also, combed cotton yarn in which the fibres are straightened and parallel to each other, have smooth surfaces [7].

Furthermore, no studies have been found so far on the effect of different sizing recipes on the mechanical properties (breaking strength, elongation at break, hairiness, friction coefficient) of carded and combed cotton ring yarns with various thicknesses. This study is an attempt to fill this gap and endeavours to add a little more knowledge to what is already known in this domain.

EXPERIMENTAL WORK

Materials and Method

Materials

• ***Yarns***

100% cotton carded and combed single yarns, whose specifications are given in table 1, were used in the experiments. While the latter in fabric codes represent the yarn type and yarn count together, the number represents the sizing agents.

Table 1

THE SPECIFICATIONS OF YARNS

Yarn code	Raw material	Yarn type	Yarn count (Ne)
A0	100% Cotton	Ring (Combed)	Ne 20/1
B0	100% Cotton	Ring (Combed)	Ne 30/1
C0	100% Cotton	Ring (Combed)	Ne 40/1
D0	100% Cotton	Ring (Carded)	Ne 16/1
E0	100% Cotton	Ring (Carded)	Ne 20/1
F0	100% Cotton	Ring (Carded)	Ne 30/1

• ***Size materials***

The following size materials and agents, provided by industry, were used: i) Emsize E6 (potato starch); ii) Ensize TX11 (synthetic polyvinyl alcohol); iii) Emsize CMS60 (carboxyl methyl cellulose); iv) Ensize TX79 (natural polyvinyl alcohol); v) Wachs (softener).

The friction between the reed and warp yarns are high, therefore slippery sizing film is required. In order to increase the slipperiness of sizing film, watches were used as softener.

Methods

• ***Yarn sizing***

The sizing process was carried out in weaving workshop of in-house by CCI laboratory sizing machine (SS560, Taiwan). Sizing consisted of three steps; yarns were immersed in sizing liquor in the first step. In the second, a pair of squeezing rollers, enabling the regulation of the squeezing pressure, sent away too much sizing agent. In the last step, yarns were dried in a heating chamber.

Four different sizing liquors were prepared in Finishing Laboratory of in-house with a size percentage of 10%, 5%, 10% and 5%, using sizing recipes containing Emsize E6, Ensize TX11, Emsize CMS60 and Ensize TX79, respectively. Wachs, a percentage of 2%, was also added to all size recipes as softener. Size liquors were heated up to 90°C and scoured at 90°C during 20 minute. While temperature of sizing chamber was set 90°C, temperature of heating chamber was set 86°C during the sizing process. All conditions mentioned did not change during the process, so it can be claimed that the conditions for all the yarns tested were the same.

• ***Test methods and testing instruments***

Firstly, sized and unsized yarns were conditioned at standard atmosphere conditions during 24 hours. In

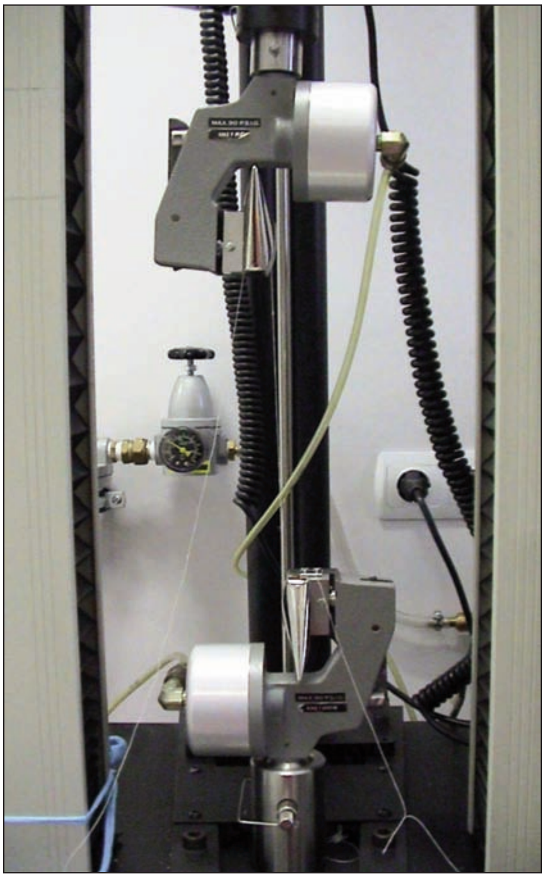

Fig. 1. Multipurpose Strength Tester

Fig. 2. Hairiness Tester

order to repeat the tests, all tests were performed also at standard atmosphere conditions in Physical Testing Laboratory of in-house.

Unseized yarns' twists, given in table 1, were determined by electronic twist measurement device according to EN ISO 2061 [8]. Measurements were performed in accordance with the Open-Close method, because yarns are single yarns. Measurement length was 25 cm. And then twist per meter was calculated.

Breaking forces and elongation at breaks of yarns were measured by INSTRON Multipurpose Strength Tester (4411, USA), shown in figure 1, according to EN ISO 2062 at 100 mm/min [9]. Measurement length was 200 mm. Load cell, whose capacity is 500 N, was used.

Hairiness of yarns was determined by Uster Zweigle Hairiness Tester (5, Switzerland), shown in figure 2, according to ASTM D5647-07 at 50 m/min. The input tension was 5 cN [10]. Measurement length was 100 m.

Friction tests were also performed by Lawson Hemphill Dynamic Friction Tester (CTT, USA) according to ASTM D3108 at 100 mm/min [11]. Co-efficient of friction between yarns and solid material, shown in figure 3, were determined. The input tension was 15 cN.

• ***Statistical evaluation***

Breaking test results were evaluated statistically by ANOVA according the General Linear Model with SPSS 15.0 software package. In order to analyse the effect of sizing and yarn count, multivariate analysis

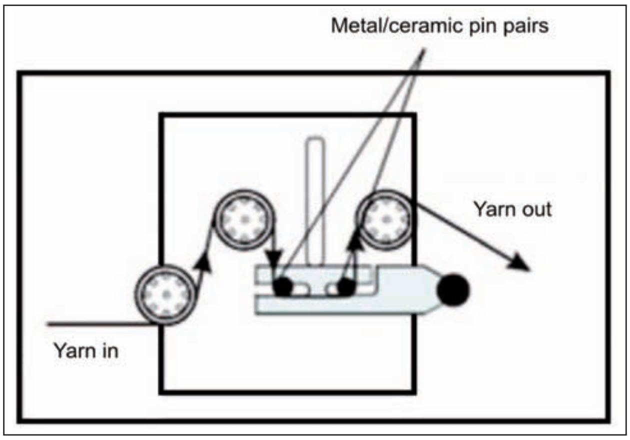

Fig. 3. Yarn to solid material friction in Dynamic Friction Tester [12]

was made for the two groups of yarns: one including combed yarns and the other including carded yarns. Significance degrees (*p*), which were obtained from ANOVA, were compared with significance level (α) of 0.05. The effect, whose significance degree was lower than 0.05, was interpreted as statistically important.

Besides, the effect of yarn type on breaking force and elongation at break of yarns was evaluated by *t* tests for combed and carded yarns, whose counts were the same. *t* tests were done by MATLAB 6.5 with significance level (α) of 0.05 also. Hypothesis of h_0 was defined that averages were equal. If h, the calculated value, was equal to 1, h_0 would be ignored, namely; the difference between the breaking test results is statistically important.

RESULTS AND DISCUSSION

Average values of all tests results are given in table 2. The hairiness tests of yarns, coded as D1, F1, A3, B3, E3, F3, F4, could not be performed, because bending rigidity of these yarns increased with sizing.

Yarn twist test results

Yarn twists are shown in figure 4. From the figure, it is seen that yarn twist increases expectedly when the yarn count increases, namely the yarn becomes thinner, for A0, B0 and C0, which were combed yarns, and for D0, E0, and F0, which were carded yarns. While the twist of A0 is almost equal to the twist of E0, the twist of B0 were almost equal to the twist of F0, which were the combed and carded yarns with the same count.

Table 2

TENSILE, HAIRINESS AND FRICTION PROPERTIES OF YARNS

Yarn code	Twist (T/m)	Breaking force (gf)	Elongation at break (%)	Hairiness (S3)*	Coefficient of friction (μ)
A0	668	491,0	9,76	3141	0,23
B0	857	362,4	8,88	2104	0,22
C0	1008	187,0	6,16	1880	0,21
D0	631	600,4	10,85	4317	0,25
E0	682	473,0	9,17	3576	0,24
F0	831	322,8	8,50	2470	0,23
A1	-	609,9	7,09	31	0,22
B1	-	397,6	7,76	14	0,21
C1	-	266,4	5,45	11	0,20
D1	-	706,6	8,89	-	0,24
E1	-	611,4	7,24	40	0,23
F1	-	334,6	6,08	-	0,22
A2	-	589,1	8,71	12	0,18
B2	-	393,3	8,31	8	0,18
C2	-	265,6	5,56	3	0,17
D2	-	749,0	9,38	16	0,20
E2	-	612,5	8,54	13	0,19
F2	-	361,1	7,41	5	0,18
A3	-	620,8	8,95	-	0,20
B3	-	392,3	8,04	-	0,19
C3	-	300,1	5,68	23	0,18
D3	-	682,9	8,61	69	0,21
E3	-	604,3	8,31	-	0,20
F3	-	371,1	7,74	-	0,20
A4	-	604,0	7,69	48	0,21
B4	-	364,1	8,20	27	0,20
C4	-	272,2	5,48	20	0,19
D4	-	675,2	8,49	78	0,23
E4	-	567,3	8,28	66	0,22
F4	-	337,8	7,31	-	0,21

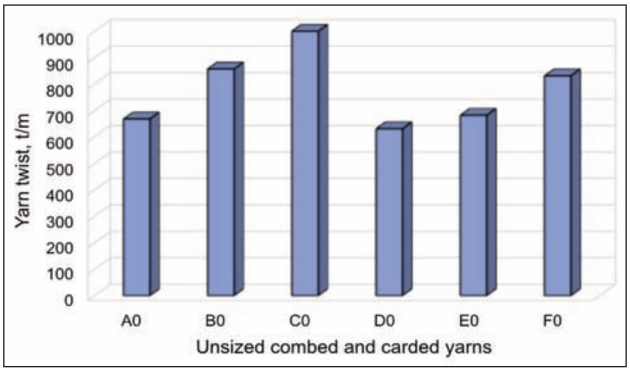

Fig. 4. Yarn twist

Breaking strength test results

Breaking force and elongation at break values of yarns are shown in figure 5 and figure 6, respectively. When we look at the effect of yarn structural properties on yarn tensile properties, it is observed that the breaking force of A0 was 26.19% higher than that of B0, whereas the breaking force of B0 was 48.4% higher than that of C0. While the breaking force of D0 was 21.22% higher than that of E0, the breaking force of E0 was 31.75% higher than that of F0. Similarly, A0 had 9.02% higher elongation at break values than B0, whereas the B0 had 30.63% higher elongation at break values than C0. While D0 had 15.48% higher elongation at break values than E0, E0 had 7.31% higher elongation at break that of F0. This is because of the fact that more fibres in cross

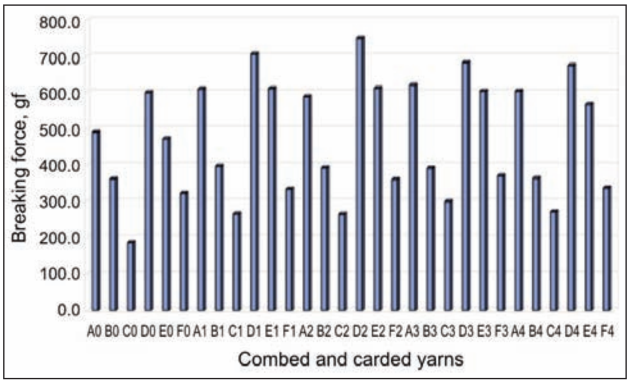

Fig. 5. Breaking force of yarns

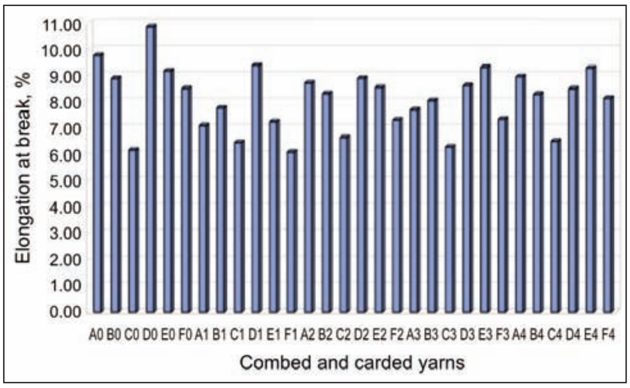

Fig. 6. Elongation at break of yarns

section of thicker yarns have more breaking strength and cause thicker yarns to elongate more.
The breaking force of A0, combed yarn, was 3.67% higher than that of E0, carded yarn, and also the breaking force of B0, combed yarn, was 10.93% higher than that of F0, carded yarn. In like manner, A0 had 6.05% higher elongation at break values than E0. Moreover, B0 had 4.28% higher elongation at break values than F0. This is due to the fact that, combed yarns are spun from longer staple fibres, which have uniform length distribution. Therefore combed yarns had more twists and resisted more to the forces along their axis during the breaking tests.
When we look at the effect of sizing on yarn tensile properties, it is seen that all size agents, used in experimental, raised the breaking force of combed and carded yarns: the highest increments is observed between A0-A3, B0-B3, E0-E3, sized with carboxyl methyl cellulose and C0-C2, D0-D2, E0-E2, sized with synthetic polyvinyl alcohol.
On the other hand, all sizing agents reduced the elongation at break values of sample yarns. Carboxyl methyl cellulose reduced the elongation at break of A0, C0 and F0 minimum. And also synthetic polyvinyl alcohol diminishes the elongation at break of B0, D0 and E0 minimum.

Hairiness test results

Hairiness of yarns is shown in figure 7. From the figure, it is observed that while the hairiness of A0 was 33.01% higher than that of B0, the hairiness of B0 was 10.65% higher than that of C0. Similarly, D0 had 17.16% higher hairiness values than E0, whereas E0 had 30.93% higher hairiness values than F0. This is because of the fact that, thinner yarns have more twists and also less number of fibres in their cross sections. For this reasons, they have less hairiness.
It is seen that the hairiness of A0 was 12.16% lower than that of E0, whereas the hairiness of B0 was 14.82% lower than that of F0. Because longer and collimated staple fibres, in the structure of combed yarns, are twisted more uniformly. This will decrease the unevenness of yarn, twist and yarn hairiness.
It is observed that the effects of sizing agents on hairiness were almost the same. The hairiness of yarns reduced between 98.15% and 99.84% after sizing. This is due to the fact that size agents stick the surface fibres to the yarn surface.

Friction test results

Friction coefficients of yarns are shown in figure 8. From the figure, it is seen that the friction coefficient of A0 was 4.35% higher than that of B0, whereas the friction coefficient of B0 was 4.55% higher than that of C0. While the D0 had 4% higher friction coefficient values than E0, E0 had 4.17% higher friction coefficient values than F0. This probably results from the fact that the thinner yarns have less number of surface fibres. This reduces the friction between fibres and metal/ceramic pin pairs of Friction Tester.
While the friction coefficient of A0 was also 4.17% lower than that of E0, the friction coefficient of B0 was also 4.35% lower than that of F0. This is because of the fact that combed yarns are constituted by uniformly twisted fibres and thereby have more smother surface than carded yarns.
The friction coefficient of all yarn samples declined with sizing. Because, sizing agents stick the fibres to the yarn surface. So, unevenness and roughness of yarn therefore decreases. The biggest diminish is observed for the A2, B2, C2, D2, E2 and F2, sized with synthetic polyvinyl alcohol, approximately 20%, whereas the second reduce is seen for the A3, B3, C3, D3, E3 and F3, sized with carboxyl methyl cellulose, approximately 15%.

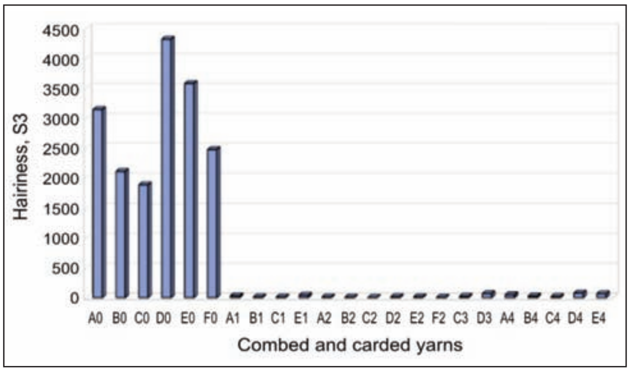

Fig. 7. Hairiness of yarns

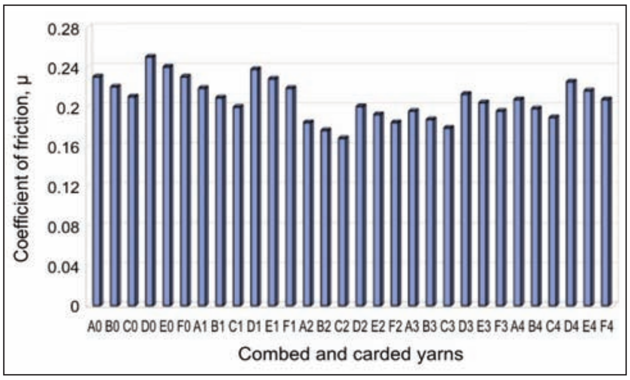

Fig. 8. Friction coefficient of yarns

Statistical results

From the results of ANOVA, made for combed and carded yarns separately, it can be concluded that the effect of yarn count and sizing on the breaking strength and the elongation at break of both combed and carded yarns are statistically important at the significance level of 0.05, getting the *p*-value of (0.000) for all analysis.
From the results of *t* tests, performed for breaking strength of combed and carded yarns, sized different sizing agents, with the same count separately, it can be deduced that the differences of breaking strength averages (B0 and F0, B1 and F1, B2 and F2, B3 and F3, B4 and F4, A4 and E4) are statistically important at the significance level of 0.05.
From the results of *t* tests, performed for elongation at break of combed and carded yarns, sized different sizing agents, with the same count separately, it can be concluded that yarn type affected the elongation at break of yarns sized with different sizing agents statistically (α = 0.05).

CONCLUSIONS

Statistical and experimental studies were conducted within the scope of this study to determine the effects of sizing and yarn count, yarn type, which are yarn important structural parameters, on the breaking strength, elongation at break, hairiness and coefficient of friction. It was found that the mentioned parameters affected the physical properties of 100% cotton carded and combed single ring yarns:

It is observed for both combed and carded yarns that thinner yarns were twisted more with the decreasing number of fibres in cross sections of thinner yarns. The combed and carded yarns, with the same count, had almost the same twist.

The breaking force and the elongation at break of combed and carded yarns increased with the decrease in yarn count expectedly, because of the more fibres in cross section of thicker yarns.

Combed yarns, which were spun from longer staple fibres, whose lengths were uniformly distributed, showed better performance during tensile tests. So they had better breaking strength and elongation at break values than carded yarns.

It is observed that hairiness of thinner yarns, which had less number of fibres in their cross sections and more twists, were lower than those of thicker yarns.

Hairiness of combed yarns, which were constituted from longer staple fibres and also parallel to each other, was better than those of carded yarns with the same count.

It is seen that friction coefficients of thinner yarns, that had more twist and less number of fibres in their surfaces and thereby had more smother surfaces, were lower than those of thicker yarns.

Furthermore, friction coefficients of combed yarns, which were comprised of uniformly twisted fibres and thereby had smother surfaces, were lower than those of carded yarns with the same count.

While the braking forces of all yarns increased with all sizing agents used in this study, elongation at break of yarns decreased with sizing agents.

It is observed that the hairiness of yarns sized with all sizing agents used in this research decreased, because of the fact that sizing agents fix fibres to the yarn surfaces. The hairiness tests of some yarns could not be performed, because of increment in bending rigidity of these yarns with sizing.

The friction coefficients of yarns, determined by means of friction tester, decreased with sizing.

Synthetic polyvinyl alcohol and carboxyl methyl cellulose, sizing agents, have the best effects on the frictional and tensile properties of 100% cotton ring yarns. Consequently, the 100% cotton combed ring yarns show better performance than in tensile tests before and after sizing. It can be concluded from the results that sizing treatment improves the tensile as well as the frictional properties of 100% cotton carded and combed ring yarns. As a result, weaving performance of sized cotton ring yarns were enhanced. The increments in the performance of sized yarns results from not onlyincrease in the breaking strength but also diminish in friction coefficients of sized yarns.

BIBLIOGRAPHY

[1] Schwarz, I.G., Kovacevic, S., Dimitrovski, K. *Analysis of changes in mechanical and deformation properties of yarn by sizing*. In: Textile Research Journal, 2011, vol. 81, issue 5, p. 545.

[2] Behera, B.K., Pakhira, A. *Evaluation of the weavability of polyester-fibre multifilament sized yarn*. In: Journal of the Textile Institute, 1998, vol. 89, issue 3, p. 522.

[3] Maatoug, S., Ladhari, N., Sakli, F. *Evaluation of the weavability of sized cotton warps*. In: AUTEX Research Journal, 2007, vol. 8, issue 4, p. 239.

[4] Behera, B.K., Joshi, V.K. *Effect of sizing on weavability of Dref yarns*. In: AUTEX Research Journal, 2006, vol. 6, issue 3, p. 142.

[5] Jaouachi, B., Ben Hassen, M., Saklı, F. *Strength of wet spliced denim yarns after sizing using a central composite design*. In: AUTEX Research Journal, 2009, vol. 7, issue 3, p. 159.

[6] Jaouachi, B., Ben Hassen, M., Saklı, F. *Optimisation of the behaviour of sized wet spliced yarns*. In: AUTEX Research Journal, 2009, vol. 9, issue 1, p. 1.

[7] Mahadevan, M. G. *Textile spinning, weaving and designing*. In: Abhishek Publications, 2009, pp. 16–17.

[8] ISO EN 2061. Textiles – Determination of twist in yarns – Direct counting method, 2010.

[9] EN ISO 2062. Textiles – Yarns Form Packages – Determination of Single-End Breaking Force and Elongation at Break, 1995.

[10] ASTM D5647-07. Standard Guide for Measuring Hairiness of Yarns by the Photo-Electric Apparatus, 2012.

[11] ASTM D 3108. Standard Test Method for Coefficient of Friction, Yarn to Solid Material, 2013.

[12] Kilic, G.B., Sülar, V. *Frictional properties of cotton-tencel yarns spun in different spinning systems*. In: Textile Research Journal, 2012, vol. 82, issue 8, p. 755.

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The influence of air-jet and vortex yarn on functionality of woven fabric

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REZUMAT – ABSTRACT

Influența firelor filate cu jet de aer şi vortex asupra funcționalității țesăturii

Obiectivul acestui studiu este de a analiza influența structurii firelor filate cu jet de aer şi vortex asupra funcționalității țesăturii. În cadrul studiului, au fost analizate firele cu jet de aer şi vortex comparativ cu firele convenționale filate pe maşina de filat cu inele, din amestecul de 65% PES / 35% fibre CO şi finețe 20 tex.
Țesătura cu legătură diagonal T1/3Z a fost realizată din firul filat cu jet de aer, vortex şi filat cu inele în direcția bătăturii, cu două desimi diferite de bătătură (20 şi 30 fire pe cm).
În prima parte a studiului, au fost analizate structura, proprietățile fizice şi mecanice ale firelor filate cu jet de aer, vortex şi filate cu inele, în timp ce în a doua parte a studiului a fost analizată influența firelor utilizate în direcția bătăturii asupra funcționalității țesăturii.
Studiul s-a concentrat în principal pe proprietățile fizice, mecanice, precum şi pe proprietățile de permeabilitate ale țesăturii filate cu jet de aer şi vortex în direcția bătăturii, în comparație cu țesăturile cu fire convenționale filate cu inele în direcția bătăturii, cu compoziție chimică şi finețe a firelor similare.
Rezultatele studiului au evidențiat structura ideală a firului în direcția bătăturii (filate cu jet de aer sau vortex) care aproximează cel mai bine caracteristicile firelor filate cu inele, datorită mecanismului cursor-fus şi a celei mai uniforme structuri, în principal datorită inserării torsiunii reale.

Cuvinte-cheie: fir filat cu jet de aer, fir vortex, fir filat cu inele, țesătură, proprietăți mecanice şi de permeabilitate

The influence of air-jet and vortex yarn on functionality of woven fabric

The basic intention of the research is to analyse the influence of air-jet and vortex yarn structure on woven fabric functionality. With the research, the air-jet and vortex yarn from the mixture of 65 % PES / 35 % CO fibres and fineness 20 tex were analysed. For comparison, the conventional ring-spun yarn was chosen from the mixture of 65 % PES/35 % CO fibres and fineness 20 tex.
The woven fabric in the twill weave T1/3Z was produced from the air-jet, vortex and ring-spun yarn in the weft direction with two different weft densities (20 and 30 yarns per cm).
In the first part of the study, the structure, physical and mechanical properties of the air-jet, vortex and ring-spun yarn were analysed, while in the second part of the research, the influence of used yarn in the weft direction on the functionality of woven fabric was studied.
The research was focused mainly on physical, mechanical properties as well as permeability properties of woven fabric with air-jet and vortex yarn in the weft direction in comparison with woven fabric with conventional ring-spun yarn in the weft direction, with equal chemical composition and fineness of yarn.
The research results was shown which yarn structure in the weft direction of woven fabric (air-jet or vortex) the most closely approximates the characteristics of the ring-spun yarn, which has because of ring-traveller-spindle mechanism ideal and the most even structure, mainly because of the insertion of the true twist.

Keywords: air-jet yarn, vortex yarn, ring-spun yarn, woven fabric, mechanical and permeability properties

INTRODUCTION

The conventional ring-spinning technology based on the ring-traveller-spindle mechanism, which influences on the true twist insertion of the ring-spun yarn. Mentioned mechanism is almost the same for more than 150 years [1]. The main reason of that is even structure of the ring-spun yarn, wide range of fineness, good mechanical properties that are in the close connection with the number of turns per meter that is the highest for ring-spun yarn in comparison with new spinning techniques [1–3].

In the last few years, many researches were considered with the ring-spun yarn structure in comparison with new spinning techniques such are rotor spinning and air-jet spinning technique [1, 4].

Rotor spinning allows much higher levels of productivity than ring-spinning [1]. On the other hand, the second objective has not yet been achieved because of the structure of rotor yarn, which also limits the fineness of count that can be spun. Perhaps the biggest current obstacle facing rotor spinning is the fact that it is limited to coarse and medium yarn counts (16 tex to 120 tex) while ring-spinning excels in the medium to fine counts (finer than > 16 tex).

Yarn manufacture using the air-jet primarily produces fascinated yarns using the false twist principle. Hence, we discuss about the principle of false twisting before going into actual air jet spinning.

The idealized structure of the fascinated yarn consists of parallel fibres held together by wrapper fibres. The wrapper and core fibres are composed of same staple fibre material. Since there is no real twist in the core, this type of yarn structures facilitates high production rates.

The tenacity of the fascinated yarns spun with air jet depend on the yarn count. The coarser yarns are weaker than the finer yarns for the same fibre type. Contrary to the expectation, yarns produced with finer fibres show lower tenacity compared to the yarns produced with coarser fibres.
The reason for the above observations is that the strength of the fascinated yarns is derived from the amount of wrapper fibres and the intensity of wrapping. The edge fibres are the ones that ultimately are converted into wrapper fibres. The number of edge fibres is limited to the surface of the yarn and are independent of the number of fibres in the core [1–3].
Finally, the vortex spinning is hailed as a revolutionary new technology it can also be viewed as a natural development in the technology of fasciated yarn production. From the earliest inception of fasciated yarns, it was evident that there were limitations, which precluded its wide acceptance [5].
Murata Vortex spinning technology is a modified form of jet spinning which has attracted a lot of attention because of its advantages over ring-spinning, open end and air-jet spinning. It has a high productivity rate, its yarn structure is similar to ring yarn, low hairiness and most important; it is possible to use a wider fibre length range to spin a wider yarn size production rage for 100% cotton [5–10].
Above-mentioned facts about the ring-spun yarn and especially air-jet and vortex yarn were the basic reason to deal with the influence of air-jet and vortex yarn structure on woven fabric functionality in comparison with conventional ring-spun yarn in the weft direction.

Ring-spinning

The American Thorp invented the ring-spinning machine in the year 1828. In 1830, another American Jenk, contributed the traveller rotating on the ring. In more than 150 years that have passed since that time, the machine has experienced considerable modification in detail, but the basic concept has remained unchanged.
The ring-spinning machine has been the most widely used form of spinning and it will continue for some more time, because it has unique advantage over new spinning technologies. It is universally applicable, most of the textile fibres can be spun to required fineness. The yarn spun from this machine demonstrates excellent quality features like uniform structure and good strength. It is easy to operate as compared to other spinning machines. It is flexible as regard to quantities in terms of blend and lot sizes. For these reasons, new spinning processes (with the exception of rotor spinning) have difficulty in gaining wide spread acceptance.
Disadvantages of ring-spinning system are low production and that machine generates more heat.
In ring-spinning, the fibre mass of the rove is reduced by a drafting unit. The twist inserted moves upwards and reaches the fibres leaving the drafting unit. The fibres lay around one another in concentric helical path. The normal force encountered by the fibres enhances the adhesive forces between the fibres and prevent fibres from flying or slipping past each other under the tensile strain.
It is the process of attenuating the roving strand until required final yarn count achieved and inserting twist to the fibres by means of a rotating spindle and winding the yarn on a bobbin. These three stages take place simultaneously and continuously. The ring yarn is characterized by high flexibility in the use of the raw material, the yarn count and the yarn character. It possesses a high degree of strength and yarn hairiness [1–3].

Air-jet spinning

With air-jet spinning a draw frame sliver fed from a can is passed to a drafting arrangement, where it is attenuated by a draft in the range of 100–200. The fibre strand delivered then proceeds to two air jets arranged directly after the drafting arrangement. The second jet is the actual false-twist element.
In air-jet spinning, a sliver is fed to the drafting system; the drafted sliver enters a spinning nozzle. The leading end of the fibres forms the parallel yarn core; the free fibre ends are wound around the yarn core by the air in the spinning nozzle. The air-jet yarn is then wound onto a package.
The air-jet-spun yarn structure consists of core fibres without significant twist and covering fibres with a genuine twist, which ultimately produces the corresponding yarn tenacity. The specific yarn structure results in yarn tenacity between that of a ring-spun yarn and that of a rotor-spun yarn.
The air vortex generated in this jet, with an angular velocity of more than 2 million routes per minute twists the strand as it passes through so that the strand rotates along a screw-thread path in the jet, achieving rotation speeds of about 250,000 routes per minute. The compressed air reaches the speed of sound when entering the central canal of the false-twist element. Since the axial forces are very low during this rotation, only low tensions arise in the yarn [9–15].

Vortex spinning

Vortex spinning technology was introduced by Murata Machinery Ltd. Japan in 1997. This technology is best explained as a development of air-jet spinning, making use of air jets for yarn twisting. The main features of Murata vortex spinning (MVS) are ability to produce yarn at 400 m/min, which is almost 20 times greater than ring-spinning frame production and low maintenance costs, a fully automated piecing system and elimination of roving frame. The yarn and the fabric properties of MVS yarn are claimed by the manufacturer to be comparable to those of ring-spun yarn.
Vortex yarn has a two-part structure: a core surrounded by wrapper fibres. The number of wrapper fibres compared to the fibre core is higher compared to the air jet spinning. During yarn formation, the leading ends of the fibres are directed towards the yarn core and the trailing ends wrap around the core

fibres. Such a structure provides the necessary fibre orientation and, at the same time, the required yarn strength.

One problem with the vortex system is significant fibre loss during the yarn formation. This is related to the problem of variations in yarn quality, which are not detectable by conventional evenness testers and sometimes only identified by weak points in the finished fabric. The path followed by the fibre in the currents created by the air jets play a crucial role in yarn quality. Most structural defects are caused by the deflection of fibres in the air jet from their ideal path [4–9].

EXPERIMENTAL

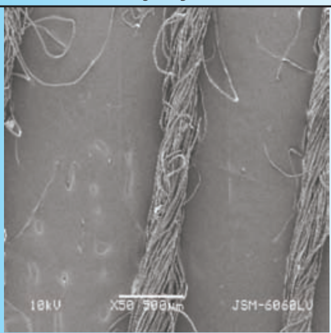
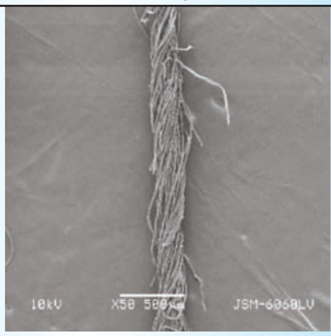
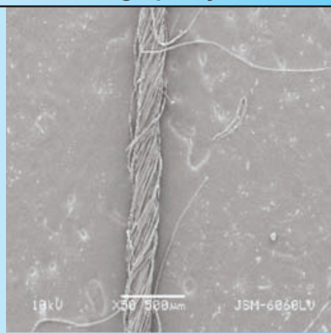
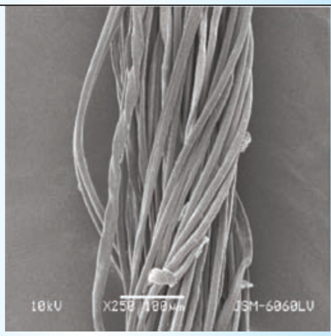
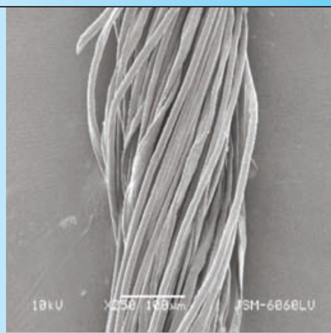
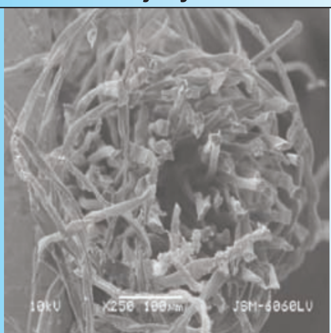
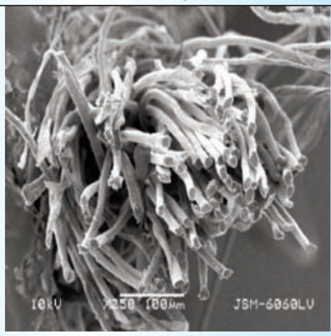
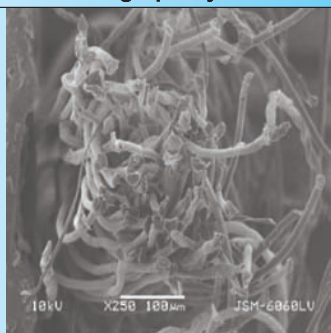
Materials

The basic intention of the research is to analyse the influence of air-jet and vortex yarn on woven fabric functionality. With the research, the air-jet and vortex yarn from the mixture of 65 % PES/35 % CO fibres and fineness 20 tex were analysed. The air-jet yarn had the false twist while the vortex yarn had 695 twists/m. For comparison, the conventional ring-spun yarn was chosen from the mixture of 65 % PES/35 % CO fibres and fineness 20 tex and 789 twists/m.

For the intention of our research, six woven fabrics were designed and produced on the weaving machine Minifaber (Italy) with Jacquard mechanism TIS (France). The woven fabrics were produced in the twill weave T 1/3 Z from the air-jet (A20, A30), vortex (V20, V30) and ring-spun yarns (R20, R30) in the weft direction with two different weft densities (20 and 30 yarns per cm).

Table 1 presents the SEM images of air-jet, vortex and ring-spun yarn in the weft direction of fabric. Ring-spun yarn is produced using true twist insertion from the outer to inner layer and has the most even structure (table 1: Ring-spun yarn – longitudinal and cross-sectional view). On the other side the air-jet yarn is produced using false twist insertions caused by air vortex generated in two jets, with an angular velocity of more than 2 million routes per minute.

Table 1

Magnif.	Samples (longitudinal view)		
	Air-jet yarn	Vortex yarn	Ring-spun yarn
50			
250			
	Samples (cross-sectional view)		
	Air-jet yarn	Vortex yarn	Ring-spun yarn
250			

Because of that the air-jet-spun yarn structure consists of core fibres without significant twist and covering fibres with a genuine twist (table 1: Air-jet yarn – longitudinal view and cross-sectional view). On the contrary, the vortex yarn is produced using true twist insertion. Vortex yarn has a two-part structure: a core surrounded by wrapper fibres (table 1). The number of wrapper fibres compared to the fibre core is higher compared to the air-jet spinning.

Table 2 presents the microscope images of woven fabrics analysed with the magnifications 10 x, 20 x and 30 x.

Table 2

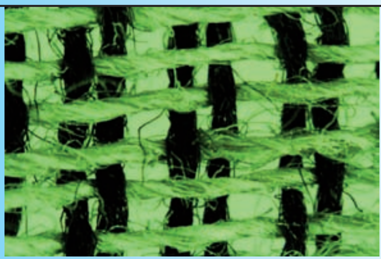
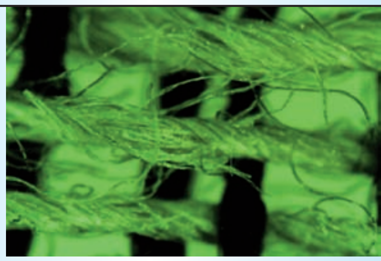
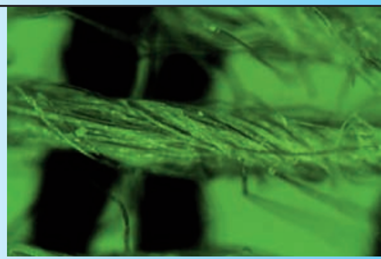
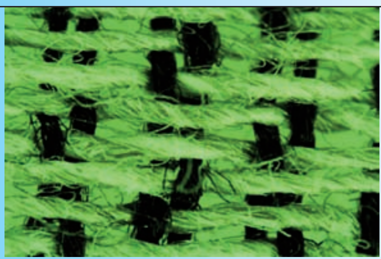
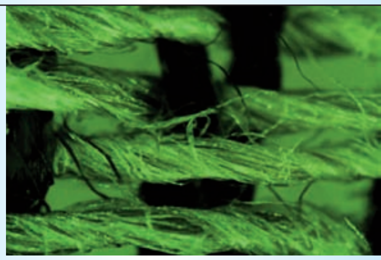
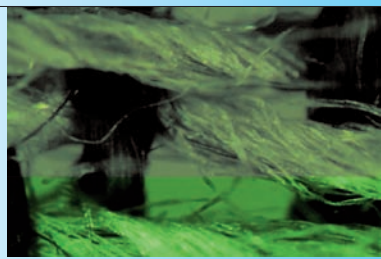
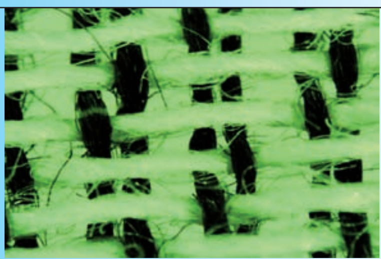
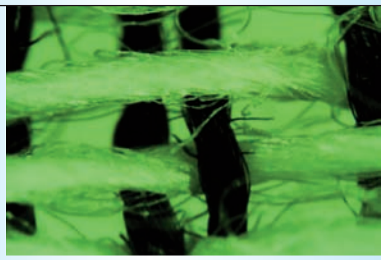
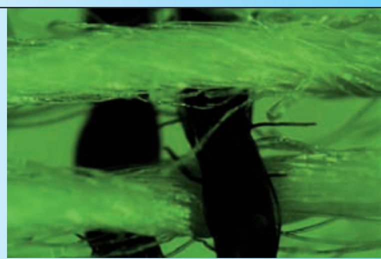
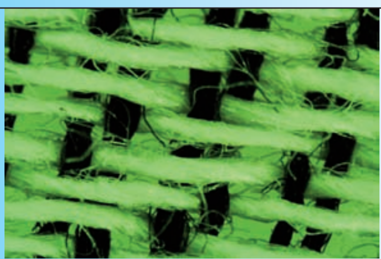
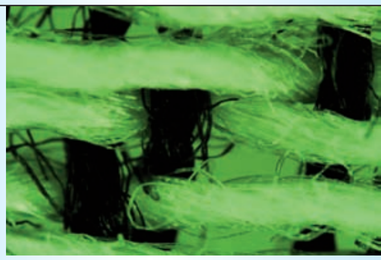
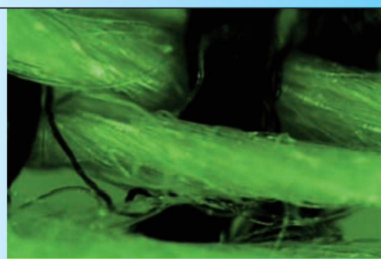
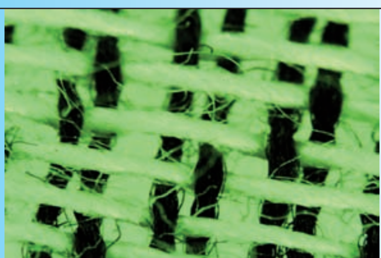
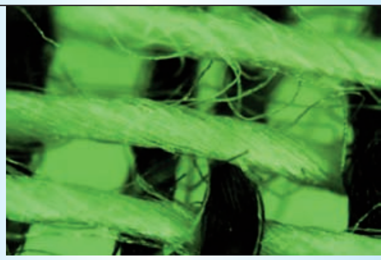
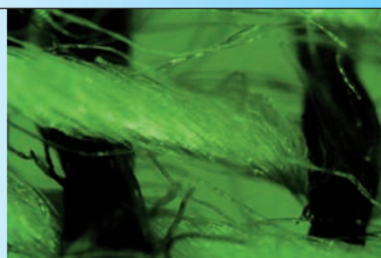
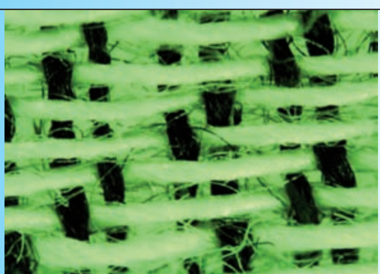
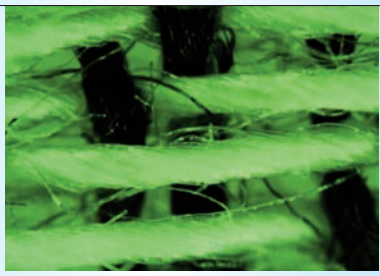
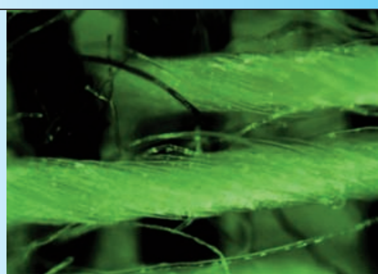
Fabric	Magnification		
	10 x	20 x	30 x
A20			
A30			
V20			
V30			
R20			
R30			

Table 3

Sample	Yarn in the weft direction	Mass, M (g/m^2)	Thickness, h (mm)	Warp density g_o (yarns/cm)	Weft density, g_v (yans/cm)	Diameter of yarn, d (µm)
A20	**Air-jet**	78.140	0.364	20.6	21.2	260.000
A30	**Air-jet**	90.040	0.383	21.6	30	214.333
V20	**Vortex**	75.740	0.379	20.8	22.8	288.333
V30	**Vortex**	91.760	0.385	21.4	31	234.333
R20	**Ring-spun**	78.860	0.363	21	21.8	235.000
R30	**Ring-spun**	94.420	0.373	20.6	29.6	200.333

The fabric mark A20 and A30 presented woven fabric with air-jet yarn in the weft direction with the weft density 20 yarns per cm (A20) and 30 yarns per cm (A30), while fabrics with vortex yarn in the weft direction was signed as V20 and V30 with two different weft densities (20 and 30 yarns per cm). The fabric with ring-spun yarn in the weft was signed as R20 and R30 with two different weft densities (table 2).
The ring-spun yarn from 100 % CO was used in the warp direction. The density in warp direction was the same for all fabrics, 20 yarns per cm. Linear density of ring-spun yarn in warp direction was 16 tex, with 537 twists/m. All yarns in the warp and weft directions had Z twist direction.
Table 3 presents the structural properties of fabrics analysed

Fig. 1. Mesdan Lab apparatus

METHODS

The first part of the research deals with mechanical properties of air-jet, vortex and ring-spun yarn, which were chosen for the research. According to mentioned above, the breaking force and elongation of yarns were measured according to ISO 2062. For each sample of yarn, the twenty-five measurements were done and breaking stress of yarn was calculated. Finally, from the stress/extension curve of each yarn, the stress and extension in the yield point and elasticity modulus were calculated using SigmaPlot 9 programme.
Further, the breaking force and breaking elongation of woven fabric were carried according to standard SIST EN ISO 13934 (Textiles – Tensile properties of fabrics-Part 1, 2013) on dynamometer INSTRON 5567 [16]. Five measurements were done for each sample. Finally, the breaking stress was calculated. The analysis of the stress/extension curve was done also using SigmaPlot 9 programme to achieve some basic viscoelastic factors, such are the stress and extension in the yield point and elasticity modulus.
In the second part of the research, some functional properties of woven fabrics analysed were carried on. Air permeability of fabrics analysed was carried on according to ISO 9237 on the five different places of each fabric [17]. Finally, the air permeability in $l/m^2 \cdot h$ was measured on the Mesdan Lab apparatus (figure 1). The measuring area was 20 cm^2.
Water vapour permeability was measured according to ASTME96:E96M [18]. Two measurements were done of each sample and finally the water vapour permeability was calculated, *WVT*, Equation (1).

$$WVT = \frac{m_{24} - m_0}{S \cdot t} \ (g/m^2 \cdot t) \qquad (1)$$

m_{24} is mass of the sample on the cup of water after 24 hours (g);
m_0 – mass of the sample on the cup of water at the beginning (g);
S – area of measuring (S = 7,065 cm^2);
t – measuring time 24 hours (h).

The experimental results (breaking stress and extension, stress and extension in the yield point, elasticity modulus, air permeability of fabrics and water vapour permeability of fabrics analysed were statistically processed by the multifactor ANOVA using StatisticXL programme. All analyses were carried out at 95% confidence level[19].

RESULTS AND DISCUSSION

Breaking stress and extension of yarns analysed

Table 4 presents the results of breaking stress and extension of air-jet, vortex and ring-spun yarn.
The results of breaking stress and extension of yarns analysed have shown that the highest breaking stress and extension was noticed for ring-spun yarn. The results of breaking stress and extension of vortex yarn present the middle value between ring-spun and air-jet yarn. The reason of the highest breaking

Table 4

Yarn	Breaking stress, σ_{br} (cN/tex)	Standard deviation, s (cN/tex)	Coefficient of variation, CV (%)	Breaking extension, ε (%)	Standard deviation, s (%)	Coefficient of variation, CV (%)
Air-jet	11.064	35.809	16.446	5.367	1.024	19.081
Vortex	16.622	38.065	11.691	7.553	0.726	9.612
Ring-spun	24.522	35.291	7.214	10.633	0.571	5.372

stress and extension of ring-spun yarn lies in the structure of ring-spun yarn, which has the highest number of twist (789 twists/m). The number of twists has an important impact on mechanical properties such are breaking stress and breaking extension.

The lowest breaking stress and extension expressed air-jet yarn, which is produced with the false twisting the sheath fibres around the core fibres. Only 5 % of the sheath fibres are wound around the core. That is the main reason for the lowest breaking stress and extension.

Stress and extension in the yield point and elasticity modulus of yarns analysed

Table 5 presents the results of the stress and extension in the yield point and elasticity modulus of yarns analysed.

The results of the stress and extension in the yield point are shown that the highest yield point (the stress and extension in the yield point) has ring-spun yarn, which means the wider region of elastic deformation. The reason lies in the structure of the ring-spun yarn, which expresses the highest twist.

The results of the elasticity modulus, which present the resistance of fabric under loading in the elastic region to the limit of elastic deformation (the yield point), show that ring-spun yarn expresses the highest elasticity modulus in comparison with air-jet and vortex yarn. Ring-spun yarn has also the highest breaking stress and extension, means that the stress/extension curve of ring-spun yarn has steeper slope in the field of elastic deformations than the curve of air-jet or vortex yarn. The lowest elasticity modulus has air-jet yarn, mainly because of false twist insertion during production of air-jet yarn, which results in the lower percentage (only 5-percents) of the sheath fibres, which are wound around the core than with vortex yarn.The number of wrapped fibres of vortex yarn compared to the fibre core is higher in comparison to the air-jet spinning process. During yarn formation, the leading ends of the fibres are directed towards the yarn core and the trailing ends wrap around the core fibres. Such a structure provides the necessary fibre orientation and at the same time, the required yarn strength which influences on the higher elasticity modulus than elasticity modulus of air-jet yarn.

Table 5

Yarn	Stress in the yield point, σ_y (cN/tex)	Extension in the yield point, ε_y (%)	Elasticity modulus, E_0 (cN/tex)
Air-jet	0.036	1.333	0.036
Vortex	0.043	1.500	0.037
Ring-spun	0.044	1.500	0.042

Breaking stress and extension of fabrics analysed

Table 6 presents the results of breaking stress and extension of fabrics analysed.

From the results of breaking stress and extension of woven fabrics, it can be found that the fabrics with the ring-spun yarn in the weft direction express the highest breaking stress and breaking extension in the weft direction (36.685 N/mm^2 and 21.00 %). The breaking stress in the weft direction is the highest with fabrics, which incorporate ring-spun yarn (R20 and R30), means for the fabrics with weft density 20 yarns/cm and 30 yarns/cm. The reason lies in the structure of the ring-spun yarn, which expresses the highest twist and influences on the highest breaking stress and extension in the weft direction.

The lowest breaking stress and breaking extension is measured with fabrics A20 and A30 that incorporate air-jet yarn in the weft direction (19.637 N/mm^2 and 14.222 %).

The reason of the lowest breaking stress and extension lies in the false twist insertion during production process of air-jet yarn, which results in the lower percentage (only 5-percents) of the sheath fibres which are wound around the core than with vortex yarn.

The results of breaking stress and breaking extension of fabrics V20 and V30 that incorporate vortex yarn are between the values of fabrics with air-jet yarn in the weft (A20, A30) and ring-spun yarn in the weft direction (R20, R30).

Table 6

Fabric	Breaking stress, σ_{br} (N/mm^2)		Breaking extension, ε_{br} (%)	
	Warp	Weft	Warp	Weft
A20	13.895	14.192	9.333	10.61110
A30	13.249	19.187	9.944	13.111
V20	12.266	19.637	8.388	14.222
V30	12.036	27.517	8.666	15.778
R20	12.779	25.881	9.722	19.388
R30	13.784	36.685	9.944	21.000

From the results of breaking stress and extension of woven fabrics, it can be also found that the structure of yarn (air-jet, vortex and ring-spun yarn) has an important impact in the weft direction. In the warp direction, the differences among the values of breaking stress and extension are minor and move between 12.036 N/mm^2 and 13.895 N/mm^2 and 8.388 % and 9.944 %.
From the results it is also seen that with the increasing weft density (from 20 to 30 yarns/cm), the breaking stress and extension increase. Mentioned results are expected.
The statistical analysis ANOVA shows a statistically important influence of the used yarn structure in the weft direction on the breaking stress and breaking extension value, especially in the weft direction.

Stress and extension in the yield point and elasticity modulus of fabrics analysed

Tables 7 and 8 present the results of stress and extension in the yield point and elasticity modulus in the warp and weft direction.
The results of the elastic limit (the stress and extension in the yield point) of woven fabrics in the warp direction show the highest value of the stress and extension in the yield point with fabric A20, which incorporate air-jet yarn. That results shown that fabric with air-jet yarn in the weft has higher stress and extension in the yield point and lower elasticity modulus in the warp direction in comparison with fabrics which incorporate vortex and ring-spun yarn in the weft direction. On the other side the elasticity modulus of fabrics R20 and R30 is the highest. Means that fabrics R20 and R30 with ring-spun yarn in the weft direction are less deformable in the elastic region on the stress/extension curve.
The results of the stress and extension in the yield point in the weft direction show that the highest yield point have fabrics R20 and R30 with ring-spun yarn in the weft direction. From the results, it is seen that fabrics V20 and V30 that have vortex yarn in the weft direction also show very high values of the stress and extension in the yield point. Means that fabrics with ring-spun and vortex yarn express higher yield point and higher limit of elastic deformations than fabrics with air-jet yarn in the weft direction.
The structure of vortex yarn is very similar to ring-spun yarn, which results in similar values of the stress and extension in the yield point of fabrics R20 and R30 with ring-spun yarn in the weft and with V20 and V30 with vortex yarn in the weft direction.
The results of elasticity modulus show that the highest value of elasticity modulus has fabrics V20 and V30 with vortex yarn in the weft. The reason of that lies in the two-component structure of vortex yarn (core and the sheath fibres).
The results also show that with increasing weft density (from 20 to 30 yarns/cm), the yield point and elasticity modulus also increases. Mentioned results are expected.
The statistical analysis ANOVA shows a statistically important influence of the structure of yarn in the weft direction on the stress and extension in the yield point value and elasticity modulus especially in the weft direction

Table 7

Fabric	Stress in the yield point, σ_y (N/mm^2)	Extension in the yield point, ε_y (%)	Elasticity modulus, E_0 (N/mm^2)
A20	0.725	3.333	0.116
A30	0.590	3.333	0.134
V20	0.276	1.833	0.126
V30	0.492	2.667	0.140
R20	0.164	2.055	0.208
R30	0.622	3.000	0.172

Table 8

Fabric	Stress in the yield point, σ_y (N/mm^2)	Extension in the yield point, ε_y (%)	Elasticity modulus, E_0 (N/mm^2)
A20	0.577	2.000	0.992
A30	1.033	3.167	0.280
V20	0.805	2.33	0.345
V30	1.548	3.333	0.326
R20	0.890	2.833	0.220
R30	1.598	3.833	0.215

Air permeability of fabrics analysed

Table 9 presents the results of air permeability of fabrics analysed.
The results of air permeability of fabrics show that the highest air permeability was measured with fabrics R20 and R30 with ring-spun yarn in the weft direction. Reason lies in the so-called ideal structure of ring-spun yarn and the highest twist of ring-spun yarn, which influences on the lower number of short projecting fibres that ensures the highest air permeability for the both weft densities, 20 and 30 yarns/cm of fabrics (R20 and R30). Fabrics A20 and V20 which incorporate air-jet and vortex yarn in the weft direction have similar value of air permeability (19.94 and 19.87 l/min·cm^2). Fabrics A30 and V30 (weft density: 30 yarns/cm) also express similar values of air

Table 9

Fabric	Air permeability, Q (l/ min·cm^2)
A20	19.94
A30	13.33
V20	19.87
V30	12.77
R20	21.58
R30	14.53

permeability, A30 (13.33 l/min·cm^2) and V30 (12.77 l/min·cm^2).

Air-jet and vortex yarn have two-component structure from the core and wrapped fibres (the sheath), which influence on the projecting fibres increase on the yarn surface and finally on the woven fabric surface. The projecting fibres on the fabric surface influence on the air permeability decrease.

The results of air permeability also show that with increasing density, air permeability of fabric decreases. The statistical analysis ANOVA shows a statistically important influence of the structure of yarn in the weft direction on air permeability of fabrics analysed.

Water vapour permeability

Table 10 presents the results of water vapour permeability of fabrics analysed.

The highest water vapour permeability was measured with fabric R20, which incorporates ring-spun yarn in the weft direction. Ring-spun yarn of fabric R20 has because of higher twist, lower number of projecting fibres on the fabric surface, which influences on higher water vapour permeability (189.137 g/m^{2}h). Contrarily, the fabrics V30 (vortex yarn in the weft) and A30 (air-jet yarn in the weft) which have, because of two-component structure (core and sheath fibres), higher number of projecting fibres on the fabric surface which prevent water vapour permeability, that is in that case lower (136.53 g/m^{2}h for fabric V30 and 121.137 g/m^{2}h for fabric A30).

The results show that with increasing density, the water vapour permeability of fabrics analysed decreases.

The lowest water vapour permeability with fabrics with warp density 30 yarns/cm was measured with fabric R30 that incorporates ring-spun yarn in the weft direction mainly because of the structure of ring-spun yarn in the woven fabric. With the density increase (from 20 to 30 yarns/cm), the structure of woven fabric in the case of the ring-spun yarn is less opened than in the case of fabric A30 (air-jet yarn in the weft) and V30 (vortex yarn in the weft) with the same weft density.

The results of water vapour permeability also show that fabrics V20 and V30 with vortex yarn in the weft show higher values than fabrics A20 and A30 with air-jet yarn in the weft. Reason lies in the structure of vortex yarn, which is two-component, but the percentage of wrapped fibres around the core is higher than in the case of air-jet yarn in the weft (fabrics A20 and A30). That means less projecting fibres on the surface of fabrics A20 and A30 which influence on the lower water vapour permeability.

The statistical analysis ANOVA shows a statistically important influence of the structure of yarn in the weft direction on water vapour permeability of fabrics analysed.

Table 10

Fabric	Water vapour permeability WVT (g/m^{2}h)
A20	138.417
A30	121.137
V20	179.406
V30	136.530
R20	189.137
R30	113.116

CONCLUSIONS

Based on the presented research of the influence of air-jet and vortex yarn structure on woven fabric functionality, the following conclusions could be drawn:

- Vortex yarn, which has similar structure to ring-spun yarn (the true twist insertion in the both cases) expresses the middle values of breaking stress and extension which move betwen the breaking stress and extension of air-jet yarn and ring-spun yarn.
- The limit of elastic deformation (the yield point) of vortex yarn is very close to the ring-spun yarn yield point value, while the elasticity modulus value lies between the elasticity modulus of air-jet yarn (false twisting) and ring-spun yarn (true twisting).
- Fabrics with ring-spun yarn in the weft direction have in general the highest breaking point and the yield point level, especially in the weft direction.
- Fabrics with vortex yarn in the weft direction have in general higher breaking point and the yield point than fabrics with ring-spun yarn in the weft direction.
- On the other hand fabrics with vortex yarn in the weft express the highest elasticity modulus, mainly because of two-component structure of vortex yarn (the core and sheath fibres) with higher value of the wound sheath fibres than with air-jet yarn (only 5 % of wound sheath fibres).
- Fabrics with vortex and air-jet yarn in the weft express similar air permeability, while fabrics with ring-spun yarn express the highest air permeability, mainly because of lower number of projecting fibres on the fabric surface of that kind of fabrics.
- On the other hand the water vapour permeability of fabrics with vortex yarn in the weft express higher value than fabrics with air-jet yarn in the weft. Fabrics with ring-spun yarn in the weft express the highest water vapour permeability.

Based on the facts presented above, it could be concluded that the incorporation of vortex yarn in the weft direction improves the breaking stress and extension and the yield point level (the limit of elastic deformations) in comparison with fabric with air-jet yarn in the weft direction and consequently the region of elastic deformations (more than 50%).

The vortex yarn in the weft direction improves the elasticity modulus level. The elasticity modulus presents the resistance of a fabric under loading in the elastic region under the stress/extension curve. Means, the woven fabrics which incorporate vortex yarn in the weft are less deformable and express a wider region of elastic deformations. The research shows that the highest breaking stress and extension and also the yield point, expresses fabric with the ring-spun yarn in the weft direction. While the breaking stress and extension and the yield point of fabric with vortex yarn in the weft lie between the values of ring-spun yarn and air-jet yarn. That shows that the structure of vortex yarn is close to the ring-spun yarn with so-called ideal structure.

Further the projecting fibres of air-jet and vortex yarn influence on the air permeability and water vapour permeability decrease in comparison with ring-spun yarn which has ideal structure and is produced using true twist insertion. The structure of vortex yarn presents the combination of the structure of ring-spun yarn (wound sheath fibres) and air-jet yarn (two component structure with lower value of wound sheath fibres – only 5-percents). That is the main reason of permeability properties of vortex yarn with measured permeability values which are between the values of ring-spun and air-jet yarn.

The research confirmed that woven fabrics with vortex yarn in weft significantly improve the mechanical and permeability properties of fabrics in comparison with woven fabrics which incorporate air-jet yarn in the weft.

BIBLIOGRAPHY

[1] Lawrence, C.A. *Fundamentals of spun yarn technology*, In: London: CRC Press, 2003, 552 p.

[2] Subhash, B.W., Barrie, F. *Engineering fundamentals of ring spinning/twisting*, over-end unwinding and two-for-one twisting in textile processes, In: Lancaster: DEStech Publications, 2015, 186 p.

[3] Tasnim N.S., Someshwar S.B. *Engineering techniques of ring spinning*, In: New Delhi: WPI Publishing, 2015, 223 p.

[4] Lawrence, C.A. *Advances in yarn spinning technology*, In: Cambridge: The Textile Institute, 2010, 431 p.

[5] Erdumlu, N., Ozipek, B., Oxenham, W. *Vortex spinning technology*, In: Textile Progress, vol. 44, no. 3-4, 2012.

[6] Han, C., Xue, W., Cheng, L., Yao, J. *Comparative analysis of traditional jet vortex spinning and self-twist jet vortex spinning on yarn mechanism and yarn properties*, In: Textile Research Journal, vol. 86, no. 16, 2016, pp. 1750–1758.

[7] Li, M., Yu, C., Shang, S. *Effect of vortex tube structure on yarn quality in vortex spinning machine*, In: Fibers and Polymers, vol. 15, no. 8, 2014, pp. 1786–1791.

[8] Pei, Z., Yu, S. *Investigation on the dynamic behavior of the fiber in the vortex spinning nozzle and effects of some nozzle structure parameters*, In: Journal of Engineered Fibers and Fabrics, vol. 6, no. 2, 2011, pp. 16–29.

[9] Zhong, Y.H., Ma, J.H., Xing, M.J. *Fiber configuration of air jet vortex spinning yarns,* In: Advanced Materials Research, vol. 834–836, 2014, pp. 1784–1788.

[10] Basu, A. *Progress in air-jet spinning*, In: Textile Progress, vol. 29, no. 3, 1999, pp. 1–38.

[11] Basal, G., Oxenham, W. *Vortex spun yarn vs. Air-jet spun yarn*, In: Autex Research Journal, vol. 3, no. 3, 2003, pp. 96–101.

[12] Ahmed, S., Syduzzaman, M., Mahmed, S., Ashique, S.M. *Comparative study on ring, rotor and Air-jet spun yarn*, In: European Scientific Journal, vol.11, no.3, 2015, pp. 411–424.

[13] Zeng, Y.C., Wan, Y.Q., Yu, C.W., He, J.H. *Controlling the air vortex twist in air-jet spinning*, In: Textile Research Journal, vol. 75, no. 2, 2005, pp. 175–177.

[14] Abdal, H.A., Hamdy, A.S., Khalil, K.A. Lim, L.H. *A novel simple one-step air jet spinning approach for deposition of poly(vinyl acetate)/hydroxyapatite composite nanofibers on Ti implants*, In: Material Science Engineering, vol. 49, 2015.

[15] Witczak, D., Golanski, J. *Air flow in the air-jet false-twist spinning chamber*, In: Fibres & Textiles In Eastern Europe, vol. 15, no. 3, 2007, pp. 45–48.

[16] *Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method*, In: ISO 13934-1:2013, 12 p.

[17] *Textiles – Determination of the permeability of fabrics to air*, In: ISO 9037: 2011.

[18] *Standard Test Methods for Water Vapor Transmission of Materials”*, In: ASTM E96/E96M: 2016, 14 p.

[19] Vik, P. Regression, *ANOVA, and the General Linear Model: A statistics primer*, In: Sage Publication, 2014, 344 p.

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Approach to evaluation of car seats fabrics performance

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REZUMAT – ABSTRACT

Evaluarea performanței țesăturilor pentru scaunele auto

Acest studiu investighează performanța țesăturilor pentru scaunele auto privind compresia, proprietățile de recuperare şi confortul fiziologic al statului pe scaun. Spuma poliuretanică, nețesutele şi țesăturile tricotate 3D Spacer sunt utilizate în mod obişnuit pentru căptuşeala (în stratul intermediar) huselor pentru scaunele auto. Studiul prezintă o abordare alternativă pentru evaluarea eficienței țesăturilor pentru scaunele auto, şi anume comportamentul lor de compresie, variația în grosime la încărcarea dinamică, proprietățile termice, rezistența la vapori de apă şi permeabilitatea la aer. Proprietățile menționate aparțin cerințelor de bază în fabricarea scaunelor auto. Sistemul de micro-tomografie a fost utilizat pentru a obține informații detaliate despre schimbarea structurii interne a probelor de țesătură, înainte şi după testul de compresie.

Cuvinte-cheie: scaune auto, compresie, recuperare, rezistență termică, micro-tomografie

Approach to evaluation of car seats fabrics performance

This paper deals with investigating performance of car seat fabrics in terms of their compression and recovery properties and physiological comfort of sitting. Polyurethane foam, nonwoven and 3D knitted spacer fabrics are commonly used as padding (in middle layer) in car seats cover. The current work presents an alternative approach to evaluate effectivity of car seat fabrics, namely their compression behaviour, variation in thickness under dynamic loading, thermal properties, water vapour resistance and air permeability. The above mentioned properties belong to basic requirements in car seat manufacturing. Micro tomography system was used to obtain detailed information about change in internal structure of fabric samples, before and after compression test.

Keywords: car seats, compression, recovery, thermal resistance, micro tomography

INTRODUCTION

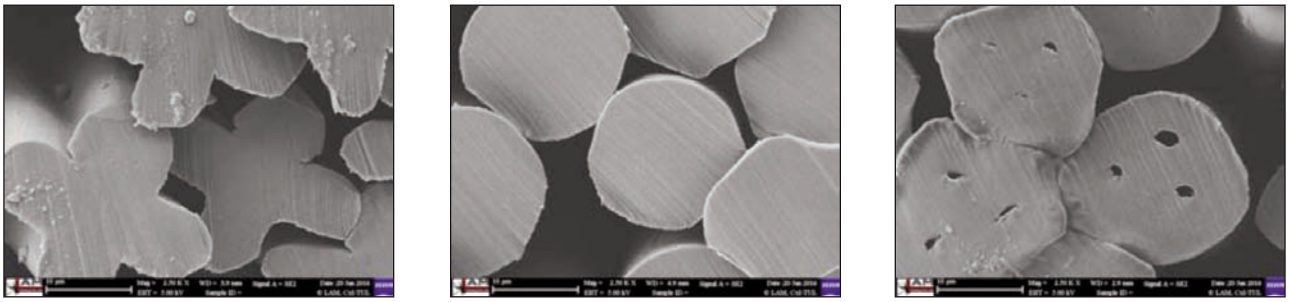
Till date, a lot of research work has been devoted to comfort in automotive seating [1–2]. A seat is built in three parts: a metal armature, foam injected in a matrix (cushion), and textile structures (fabric) which cover the foam and armature. There are approximately 3–5 kg car seat cover fabrics used in each car [3]. Car seat covers are often composed of several layers of different materials, usually polyester fabric (or leather or synthetic leather) laminated to polyurethane foam (or 3D knitted spacer or nonwoven) backing by an adhesive. Each part of car seat cover brings different properties which affect both their durability and comfort in automotive seating. More recently, car producers increasingly put emphasis on transport properties (heat, moisture, air) of car seat covers to ensure good physiological comfort of drivers. Therefore, the effect of heated seat on thermal comfort during the initial warm-up period, an ergonomic evaluation of thermal comfort inside a car, measurement of sweating bottom and others were investigated [2, 4–5]. Moisture management behaviour, thermal properties and air transport of 3D warp knitted spacer fabric (3D spacer) and polyurethane foam (PU foam), which are commonly used as padding in car seat cover, have been examined [6–9]. Thermal property of porous nonwoven materials was analysed too [10]. Further, the effect of filament cross section on the performance of automotive upholstery fabrics was evaluated from air permeability point of view [11]. Majority of researchers have reached the conclusion that appropriate choice of middle layer of car seat cover can improve physiological comfort even in complex car seats including PU cushion. But they cannot agree on whether PU foam or 3D spacer is better to be used as middle parts of car seat cover. One group of researchers prefer polyethylene terephthalate (PET) fibres for automotive application (both for top and middle layers) due to their superior properties, like a high tenacity, abrasion, light, heat and chemical aging, UV resistance, dimensional stability, recyclability etc. [8, 11–12]. The others are in favour of modified PU foam (in middle layer) because of their excellent elasticity and very good recovery to compression [12]. Study on comparison of quality for different types of seat cover padding was carried out from aspects of physiological properties and relaxation behaviour after static and dynamic loading [13]. The result of this study showed that warp knitted spacer fabrics demonstrate better recovery to compression, better thermal properties and better breathability as compared to PU foam. The other research found out that fabrics using monofilament as spacer yarn generally have higher compression resistance than multifilament yarns [8, 14]. It is important to follow changing of inner structure of cover fabric under compression (caused by driver) to understand effect on transport properties. Nowadays micro tomography analysis is an appropriate tool for it [15, 16]. To evaluate the comprehensive effectivity of car seat cover, a combination of comfort and durability behaviour must be investigated not only by tenacity and abrasion but also by studying mechanical stresses which the seats are subjected to, during the lifetime of the car. Major car manufacturers evaluate degree of car seat durability, including relaxation behaviour after cyclic loading by special equipment, which uses the robot – Occubot VI. Robot allows realistic simulation, of someone getting into and out of the seat (ingress/egress test), or of strong pulsation or vibration during driving [17]. Occubot is not often used for research in general because of high price and narrow specialization of mentioned equipment.

The current study is focused on complex evaluation of car seat fabrics in terms of their compression behaviour, thickness variation under dynamic loading, thermal properties, water vapour resistance, moisture management and air permeability. Further, the micro tomography system was used in order to obtain detailed information about change in inner structure of seat fabrics before and after compression test.

EXPERIMENTAL DETAILS

Materials

The experiment was divided into three steps. In the first step, six fabrics for car seats (group of the three different types of functional PES fibres in top layer of tested car seats in combination with different middle layers – polyurethane foam, nonwoven and 3D spacer), were analysed and compared in terms of their physiological behaviour. Second part was focused to investigation of thickness variation of tested fabrics under dynamic loading and their ability to recover compression. The third part of study was about change in internal structure of fabrics before and after dynamic compressive test by micro tomography system. The last two tests mentioned, were done with middle layer of car seat cover only. Tested materials were designed in order to understand the role of middle layer of textile sandwich car seats in their durability and physiological behaviour. Basic characteristics of all tested car seat fabrics are shown in table 1. SEM images of fibres used in weft and warp yarns from top layer of tested car seats (PES woven fabric) are shown in figure 1 and 3D images of tested materials by micro tomography system SKY SCAN 1272, are shown in figure 2. Before being tested, the samples had been washed and conditioned for 24 hours. The measurement was carried out in an air-conditioned room under constant relative humidity of 65 % and the temperature of 21°C.



a *b* *c*

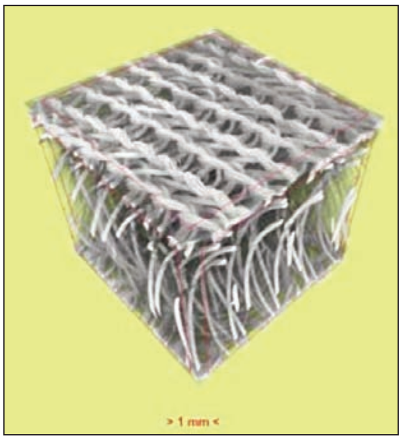
Fig. 1. SEM images of the single filaments: *a* – A1 TOP – tertalobal, *b* – A2 TOP – round, *c* – A3 TOP – hollow

Table 1

BASIC CHARACTERISTICS OF TESTED MATERIALS

	Code	Fiber content	Type of fiber	Pattern	Density warp/weft [thread/cm]	Thickness [mm]	Mass [g/m^2]
Top layer	*A1 TOP – woven fabric*	*100% PES*	*tetralobal*	*twill*	*32/18.5*	*0.81*	*233*
	A2 TOP – woven fabric	*100% PES*	*round*	*twill*	*32/18.5*	*0.79*	*235*
	A3 TOP – woven fabric	*100% PES*	*hollow*	*twill*	*32/18.5*	*0.69*	*203*
Middle layer	*B1 – weft knitted spacer*	*100% PES*	–	–	–	*4.7*	*331*
	B2 – warp knitted spacer	*100% PES*	–	–	–	*6.73*	*508*
	C1 – foam	*100% PUR*	–	–	–	*7.03*	*247*
	C2 – foam	*100% PUR*	–	–	–	*6.42*	*226*
	D – nonwoven padding	*75%PES/30%WO*	–	–	–	*4.74*	*230*

Note: Measurement of thickness were performed under 1000 Pa pressure for top layers, 100 Pa for middle layers.



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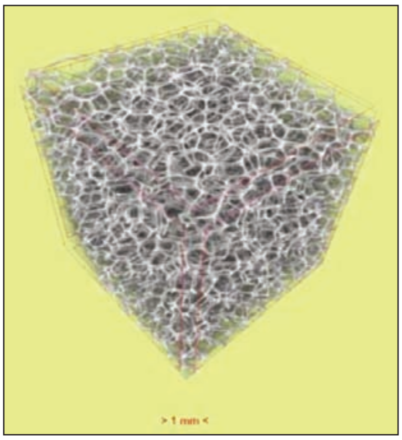
b



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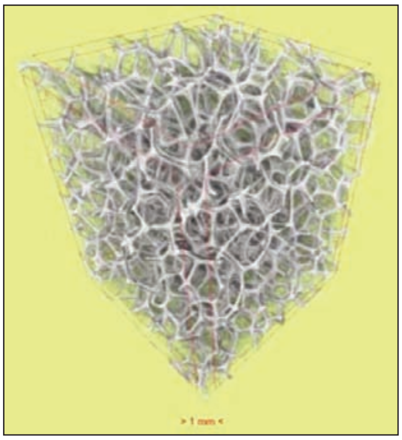

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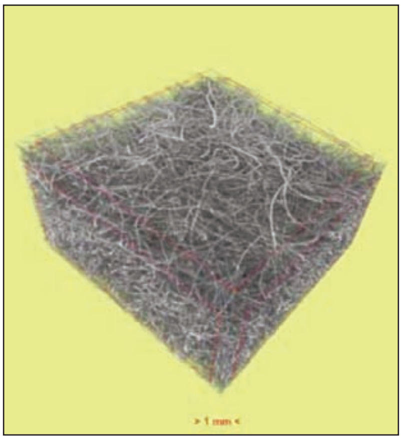


e

Fig. 2. 3D images of tested materials by micro tomography system SKY SCAN 1272: *a* – B1 – weft knitted spacer, *b* – B2 – warp knitted spacer, *c* – C1 – PU foam, *d* – C2 – PU foam, *e* – D – nonwoven padding

Methods

The performance of car seat fabrics were investigated by three ways

- ***the measurement of physiological properties*** such as thermal and water vapour resistance, air permeability and dynamic liquid transport properties of samples,
- ***the measurement of compressive characteristics***, namely thickness variation under dynamic loading and relaxation behaviour of tested samples,
- ***the analysis*** of 3D images of car seat inner structure by micro tomography system.

The results from the above mentioned methods were compared and discussed in order to understand the real performance of tested materials. Final values (means) of all tested parameters correspond to five measurements on average. The coefficients of variation for all tests do not exceed 10 % and are therefore not statistically significant.

Measurement of physiological properties

Thermal resistance and water vapour resistance

Thermal resistance Rct [m^2K/W] and water vapour resistance Ret [m^2Pa/W] of samples were investigated in accordance with standard EN 31092:1993 (ISO 11092) by Sweating Guarded Hotplate System 8.2 (SGHP).

The SGHP device is often referred to as ‘skin model‘. The test simulates the transfer processes of heat and moisture through material next to skin and measures the rate of transfer of heat or moisture in such processes. The standard defines the setting up of the following conditions: an air temperature of 35 °C and a relative humidity of 40% for measurement of water vapour resistance, and an air temperature of 20 °C and a relative humidity of 65% for measurement of thermal resistance. Both types of measurements were carried out under the air velocity of 1 m/s.

Air permeability

Air permeability of tested samples were carried out in accordance with standard EN ISO 9237:1995 using device TEXTEST FX 3300.

Dynamic liquid transport properties by MMT

The moisture management tester (MMT) was developed to quantify dynamic liquid transport properties of knitted and woven fabrics through three dimensions:

- absorption rate – time for absorption of moisture on fabric’s face and back surfaces;
- one-way transportation capability – one-way transfer from the fabric’s back surface to its face surface;
- spreading/drying rate – the speed at which liquid moisture spreads across the fabric’s back and face surfaces.

MMT works in according to AATCC Test Method 195 – 2011 and consists of upper and lower concentric moisture sensors. The specimen is held flat under a fixed pressure between the sensors while standard test solution is introduced to the back surface of the fabric. Electrical resistance changes between the upper and lower sensors which are then recorded dynamically. Based on the changes of electrical resistance, several parameters are determined. These parameters are described in detail in Hu's work and other research [18]. Two parameters were analysed in this study: OMMC [-] – overall moisture management capacity and OWTC [-] – cumulative one-way transport capacity.

OMMC is an index which indicates the overall ability of the fabric to manage the transport of liquid moisture, which includes three aspects of performance: the moisture absorption rate of the face side, one-way liquid transport ability, and moisture drying speed of the face side, which is represented by the maximum spreading speed [18].

OWTC is defined as the difference in the cumulative moisture content between the two surfaces of the fabric in the unit testing time period [18]. Negative values mean that the cumulative moisture content on the top surface of the fabric is higher than on the bottom.

Compression characteristics

Thickness variation under dynamic loading, relaxation behaviour

To study the thickness variation of middle layer of car seat fabrics under dynamic loading, the measurement device shown in figure 3 was used. This instrument was developed at Technical University in Liberec [19]. A pressure plate with contact area of 28 cm^2 (diameter is 6 cm) moved up and down with frequency of 500 cycles per min, applying a dynamic load of 20 kPa on the samples. One million of cycles were applied to each tested sample to simulate real condition of driver's sitting.

The thickness of tested samples was measured by compression tester SDL M 034A according to EN ISO 5084 both before and after dynamic loading.

Further, relaxation behaviour given by the thickness recovery of samples was investigated after above mentioned compression test, when load was removed. Specifically, the measurement was carried out immediately, 2 hours (h), 4 h and 24 h after test.

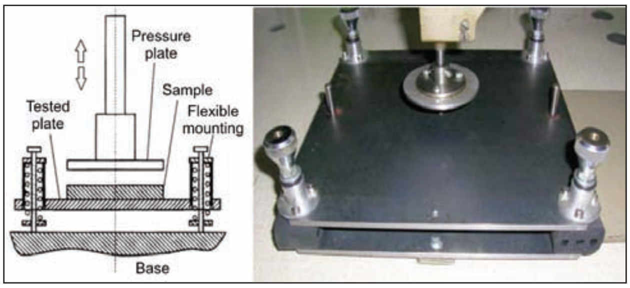


Fig. 3. Instrument for compression test [19]

All measurements of thickness were performed under 100 Pa pressure.

There are two types of spacer fabrics: warp and weft, two types of PU foam and one nonwoven's padding which were measured.

Micro tomography analysis

The computed micro tomography system SKYSCAN 1272 was used to investigate the change of inner structure of tested fabrics before and after compressive dynamic loading test. The micro CT system obtains multiple x-ray "shadow" transmission images of the object from multiple angular views as the object rotates on a high-precision stage. From these shadow images, cross-section images of the object are reconstructed using a special algorithm, creating a complete 3D representation of internal microstructure and density over an investigator-selected horizontal region in the transmission images. Measurements were taken under the following settings: image pixel size – 4,67 μm, rotation step 0.2°, rotation degrees 180°, frame averaging 3, exposure 320 ms, voltage source 40 kV. These conditions appeared as the best from both improved scanning speed and the quality of the scanned image. The above mentioned conditions are common for all tested materials. The parameters porosity [%], distribution of porosity determined by percent volume in range of pores [%] and connectivity [1/mm^3] were established from 3D images of tested materials. Connectivity is defined as the maximal number of branches that may be cut without separating the structure [20].

RESULTS AND DISCUSSION

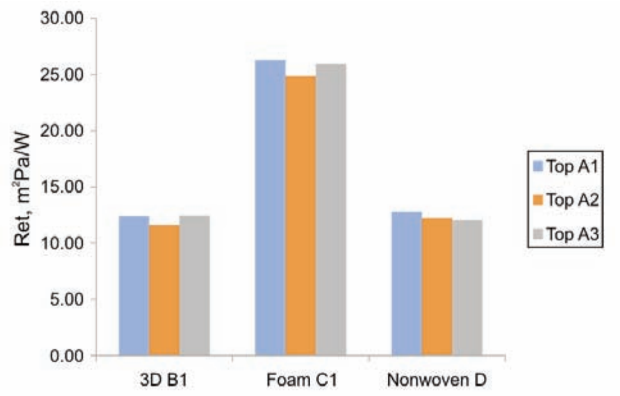
Physiological properties

To study the physiological properties of sandwich structures of car seat fabrics (different top layer connected with different middle layer by lamination), samples A1, A2, A3 in combination B1, C1, D were chosen. Totally, group of 9 car seat structures were tested by means of SGHP 8.2, MMT and TEXTEST FX 3300 to investigate transport of heat, water vapour, liquid water and air. Further, we work on an assumption, that different fibre cross section affects transport properties of samples as was presented in study of Koc [11]. Therefore top layers A1, A2, A3 are different in terms of functional PES fibres with follow cross section: round, tetralobal and hollow profile. There are 3D spacer, foam and nonwoven (B1, C1, D) used in middle layer of car seats fabric.

Thermal resistance and water vapour resistance

The results of water vapour resistance Ret [m^{2}Pa/W] and thermal resistance Rct [m^{2}K/W] are shown in figure 4.

There is significant difference among values of Ret and Rct of tested samples in the figure 4. Foam C1 shows two times bigger value of Ret than nonwoven D and 3D spacer C1. It means that foam, which is the most frequently used material in car seat fabrics,



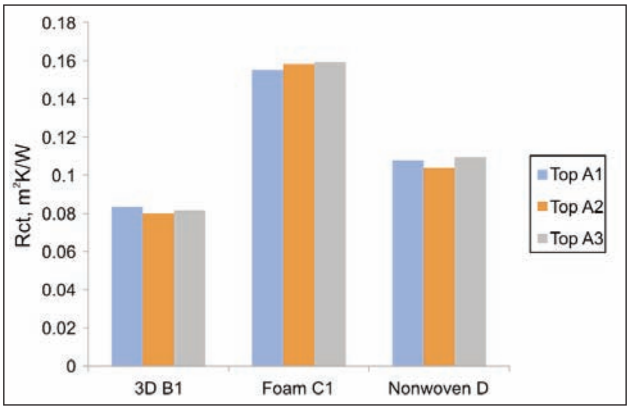


Fig. 4. Water vapor permeability (Ret) and thermal resistance (Rct) of samples

provides the least physiological comfort. The similar idea is valid for interpretation of thermal resistance results. In the case of ambient temperature inside the car, driver's body temperature is higher than temperature of car seat fabrics which results in good comfort feeling of drivers. On the other hand combination of heating of seat and low thermal insulation of car seat structures provide the faster transport of heat to skin of driver in winter. Among all the samples tested, 3D spacer fabric meets most of the aforementioned requirements. The assumption that the fibre cross section of top layer affects the transport properties of complex car seat structures has not been clearly proven. The difference of Ret and Rct values on the basis of fibre cross-section in top layers A1, A2, A3 is not significant as shown figure 4.

Dynamic liquid transport properties by MMT

Further moisture transport of top layers (A1 TOP, A2 TOP and A3 TOP) was investigated by MMT. The results of dynamic liquid transport properties are very similar for all three layers and are shown in figure 5. In summary, these results indicate that all three samples of top layer can be characterized as water proof fabrics. It means that the fabric is not wetted, the solution is absorbed very slowly or not at all, the liquid is spreading through the fabric very slowly or not at all and neither one-way transport between surfaces of fabric nor any penetration occurs (cumulative moisture content stays on the top surface where it was applied).

Air permeability

The results of air permeability of tested car seat covers are shown in figure 6. The foam has the lowest level of air permeability. Air permeability of the 3D spacer B1 is even twice as PU foam. Generally, an assumption that 3D spacers provide better comfort properties than PU foam was validated [13]. Furthermore, influence of fibres cross section (of TOP layer of car seat cover) on degree of air permeability was confirmed too [11]. TOP A3 – top layers made from hollow fibres – show higher air permeability than TOP A1 – tetralobal or TOP A3 – round cross section. Increase of air permeability value of fibres with hollow cross section against tetralobal is about 44 to 70 per cent (according to used middle layer – foam, nonwoven, 3D spacer).

▪ Compression characteristics

Thickness variation under dynamic loading, relaxation behaviour

The results of compressibility performance, particularly relaxation behaviour of car seat fabrics are shown in figure 7. The thickness variation of samples was measured both before and after dynamic compressive loading. Subsequently, relaxation behaviour of samples was determined by thickness recovery after compression test as follow: immediately after test, 0 hours (h), 2 h, 4 h and 24 h after test.

The curves showing the behaviour of materials B1, B2, C1 and C2 follow similar pattern, i.e. the thickness after dynamic loading (after 2 million cycles, at time 0 h) decreases in range between 1,6 % and 5,5% from initial value of thickness before test. After 2 million cycles, the 3D spacer B1 and B2 present the least change of thickness. On the contrary, there is significant reduction of thickness of nonwoven D (blue line) in figure 7, about 22 % of initial value of thickness.

With regard to thickness recovery, the results of all tested samples (including

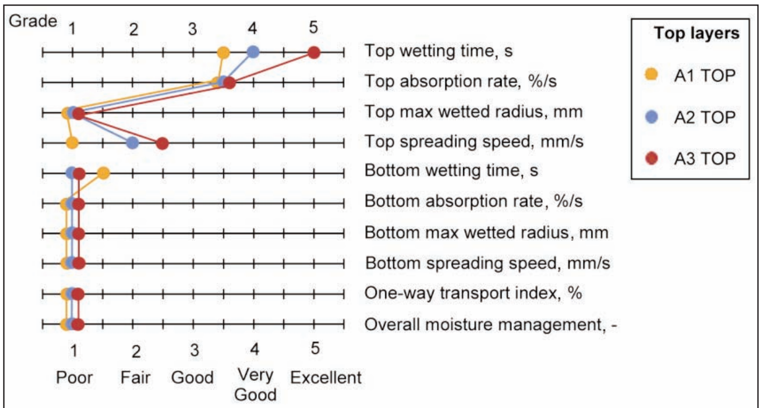


Fig. 5. Finger print of Moisture Management Properties

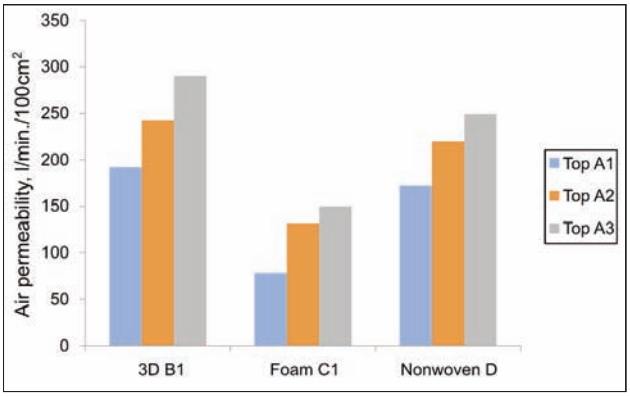


Fig. 6. Air permeability of the fabrics

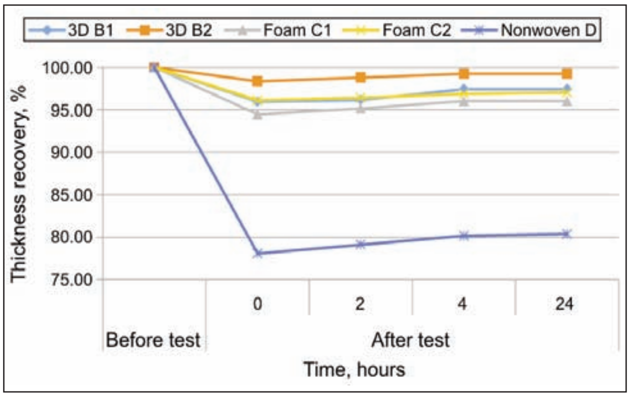


Fig. 7. Thickness recovery of tested samples within 24 hours after dynamic loading

sample nonwoven D) show a similar growth (trend) for recovery after removal of load. However sample B2 (3D warp knitted spacer) is the best one. This material has proved both the minimum thickness reduction after dynamic loading (1.6 %) and the biggest thickness recovery (99%).

- **Micro tomography analysis**

Changes in internal structure of car seat covers after loading, was investigated by means of micro tomography system SKY SCAN 1272. There is no significant difference of porosity values on account of dynamic loading, as shown in figure 8. Porosity of tested materials decreases on average by 3.5 % after loading. The nonwoven D shows the "biggest" decrease of porosity by around 8 % from original value of porosity before loading. It is interesting to note that parameter of connectivity is changing after loading particularly in nonwoven D and foam C1. Connectivity is defined as the maximal number of branches that may be cut without separating the structure. Decrease of connectivity is by 35 % after loading for PU foam C1, for nonwoven D it is about 57 %. In general, decrease of connectivity can be caused by total destruction of branches or interconnected branches by applied pressure. The assumption of interconnected branches was adopted due to dislocation of cell structure in case of PU foam. The investigation of pores distribution of tested samples has since supported these conclusions, as shown in figures 9–11. Total porosity of PU foam after loading is very similar to value before loading, but distribution of pores (frequency of individual classes of pore diameter) is changed. Part of small pores (diameter from 0 to 0.3015 mm) disappeared because of pressure. Probably neighbouring cell walls of foam are joined together, effecting in decrease of connectivity. On the other hand, there are pores with increased size of cross section after loading. It can be caused by disruption of some cell walls in PU foam structure. The similar behaviour can be observed for nonwoven D. Increase of the middle and bigger pores is probably caused by dislocation of fibres in structure. Inner structure of 3D spacer B2 has been changed quite differently. There is increase of small pores (from 0 to 0.613) since big pores were "divided" by applied load, as shown in figure 9. It is

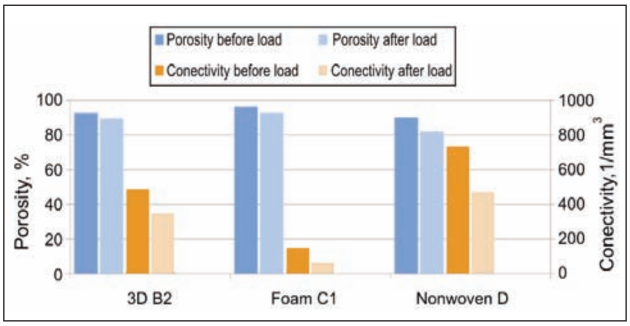


Fig. 8. Micro tomography analysis of tested car seat covers

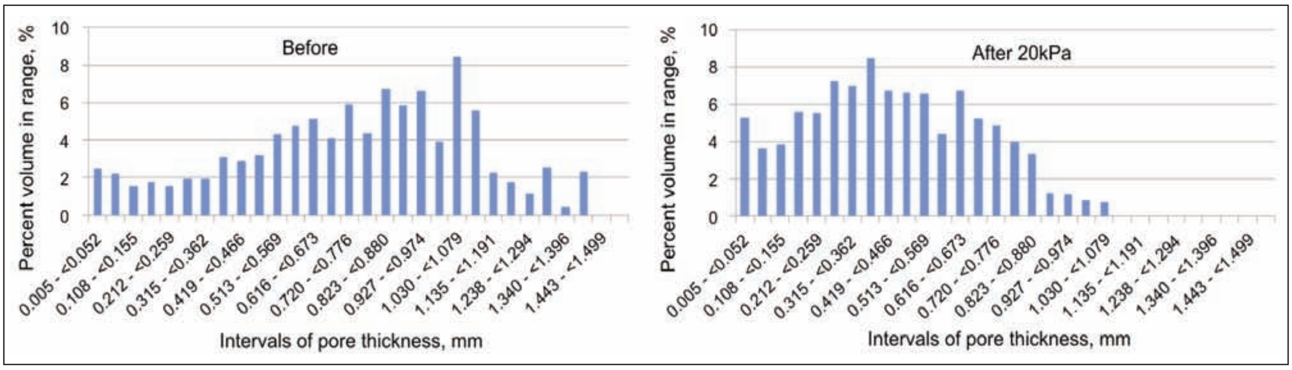
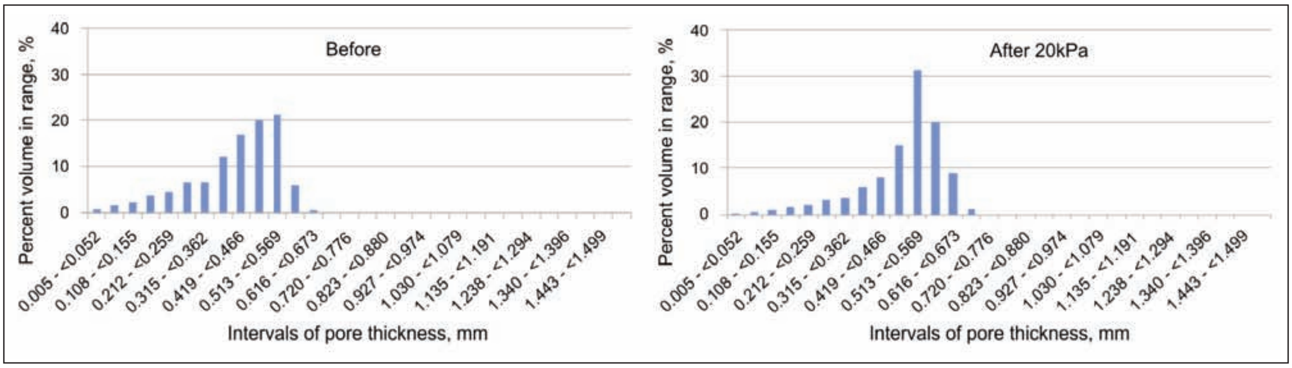


Fig. 9. Distribution of pores of 3D spacer B2 before and after dynamic load



a *b*

Fig. 10. Distribution of pores of PU foam C1: *a* – before and *b* – dynamic load

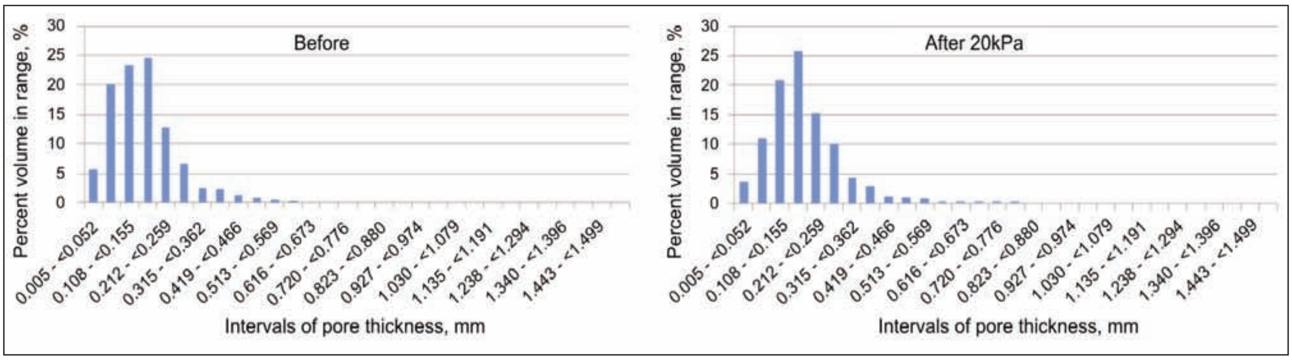


Fig. 11. Distribution of pores of nonwoven D before and after dynamic load

conceivable that shape of big pore like "" is is changed to pore with shape like "" by compression. Notably it can be mainly caused by crossing of monofilaments in middle layer of 3D spacer.

CONCLUSION

This research extends the knowledge of car seat cover that considerably affects seating comfort. Tested group of car seat covers were investigated with respect to physiological properties and relaxation behaviour after dynamic compression loading. Results show both better mechanical durability and water vapour permeability of 3D spacers than PU foam or nonwoven padding. Further, influence of fibres cross section (of TOP layer of car seat cover) on degree of air permeability was confirmed. Analysis of pore size distribution in car seat structures by micro tomography system uncover following: pores size of 3D spacer are probably decreasing by crossing (of monofilaments in middle layer) after dynamic loading, on the contrary the pores size of PU foam are enlarged because of distortion of some partition of foam cells. Taken together, these results suggest that 3D spacer is the best for automotive. Nonwoven padding of car seat cover show low water vapour permeability and low durability given by reduction of their thickness after dynamic loading. PU foam is highly resistant to dynamic loading but its physiological properties are the worst. Further research will be focused on relation between long term stress on car seat covers and their moisture management properties.

ACKNOWLEDGEMENTS

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BIBLIOGRAPHY

[1] Umbach, K.H. *Physiological comfort of seats in cars*, In: Kettenwirk-Praxis, 2000, vol. 24, issue 1, pp. 9–12.

[2] Scheffelmeier, M. and Classen, E. *Measurement methods for investigation of thermos-physiological comfort in automotive seating*, In: AACHEN Dresden International Conference, book of abstracts, 2014, p. 212.

[3] Fung, W. and Hardcastle, M., ed. *Textiles in automotive engineering*, In: Wood head Publishing limited Cambridge, England, UK, 2001.

[4] Oi, H., Tabata, K., Naka, Y., Takeda, A. and Tochihara, Y. *Effect of heated seats in vehicles on thermal comfort during the initila warm-up period*, In: Applied Ergonomic, 2012, vol. 43, issue 2, pp. 360–367.

[5] Cengiz, T.G. and Babalik, F.C. *An on the road experiment into the thermal comfort of car seats*, In: Applied Ergonomics. 2007, vol. 38, issue 3, pp. 337–347.

[6] Rothe, D., *Warp knitted spacer fabric – design and application fields,* In: Knitting Technology. 2001, vol. 4, pp. 14–16.

[7] Bagherzadeh, R., Gorji, M., Latifi, M., Payvandy, P. and Kong, L.X., *Evaluation of moisture management behaviour of high-wicking 3D warp knitted spacer fabric*, In: Fibers and Polymers. 2012, vol. 13, issue 4, pp. 529–534.

[8] Yip, J. and Ng., S.P. *Study of three-dimensional spacer fabrics: Physical and mechanical properties*, In: Journal of materials processing technology, 2008, vol. 206, pp. 359–364.

[9] Havelka, A., Glombikova V. and Mazari, F.B. *Monitoring thermophysiological comfort in the interlayer between driver and the carseat*, In: Vlákna a textile. 2015, vol. 22, issue 3/4, pp. 40–45.

[10] Zhu, G., Kremenakova, D., Wang, Y., Militky, J. and Mishra, R., *Study on the thermal property of highly porous novwoven fabrics*, In: Industria Textila. 2015, vol. 66, issue 2, pp. 74–79.

[11] Koc, K. S., Mecit, D., Bozaci B., Ornek, M. and Hockenberger, A., E*ffect of filament cross section on the performance of automotive upholstery fabric*, In: Journal of Industrial Textiles. 2015, DOI: 10.1177/1528083715598652, pp. 1–15.

[12] Jerkovic, I., Pallares, J.M. and Capdevila, X. *Study of the abrasion resistance in the upholstery of automobile seats*, In: Autex Research Journal, 2010, vol. 10, issue 1, pp. 14–20.

[13] Ye, X., Fangueiro, R., Hu, H. and Araujo, M. *Application of warp – knitted spacer fabrics in car seats*, In: Journal of the Textile Institute, 2007, vol. 98, issue 4, pp. 337–343.

[14] Chen, S. and Long, H.R. *Investigation on compression properties of polyurethane –based warp-knited spacer fabric composites for cushioning applications, Part II. Theoretical and experimental verification*, In: Industria Textila, 2014, vol. 65, issue 6, pp. 340–344.

[15] Stämpfli, R. Brühwiler P.A., Rechsteiner, I., Meyer, V.R. and Rossi, R.M. *Xray tomographic investigation of water distribution in textiles under compression – possibilities for data presentation,* In: Measurement. 2013, vol. 46, issue 3, pp. 1212–1229

[16] Doczyova, K., Glombikova, V. and Komarkova, P. *Application of microtomography in textile metrology*, In: Tekstilec. 2014, vol. 57, issue 1, pp. 4–11.

[17] Stewart, R., O'Bannon, T., Müller, M. and Beeh, F. *Creating the next generation ingress/egress robot*, In: SAE Technical Paper 1999-01-0628, 1999, doi:10.4271/1999-01-0628.

[18] Hu, J., Li, Y., Wong, A. S. W. and Xu, W. *Moisture management tester: A method to characterize fabric liquid moisture management*, In: Textile Research Journal, 2005, vol. 75, issue 1, pp. 57–62.

[19] Havelka, A. and Kus, Z. *Device for fatigue testing of textiles and multilayer textile composites*, national utility model application: 2014, Application number: 2014-30445, Registration number: 28065 http://spisy.upv.cz/UtilityModels/FullDocuments/FDUM0028/uv028065.pdf

[20] Odgaard, A. Three-dimensional methods for quantification of cancellous bone architecture, In: Bone, 1997, vol. 20, issue 4, pp. 315–328.

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The use of D-optimal design in optimization of wool dyeing with *Juglansregia* bark

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REZUMAT – ABSTRACT

Utilizarea modelului D-optimal în optimizarea vopsirii lânii cu coaja de *Juglansregia*

În acest studiu, fibrele de lână au fost vopsite folosind coaja de Juglansregia ca o nouă sursă de colorant natural. Alaunul a fost utilizat ca mordant. Metodologia de suprafață a răspunsului şi modelul D-optimal au fost utilizate pentru studierea şi optimizarea procedeului de vopsire, cu scopul de a obține intensitatea maximă a culorii după vopsirea cu extractul apos de coajă de Juglansregia. Rezultatele au arătat că intensitatea culorii fibrelor vopsite a crescut prin creşterea timpului de vopsire şi a temperaturii şi a scăzut prin creşterea valorii pH-ului băii de vopsire. A existat o valoare optimă de aproximativ 6% owf pentru concentrația de mordant. Condiția optimă pentru obținerea intensității maxime a culorii a fost următoarea: pH-ul băii de vopsire: 6, concentrația de alaun: 6,24% owf, temperatura de vopsire: 90 °C şi timpul de vopsire: 90 min.

Cuvinte-cheie: mordant, colorant natural, lână, optimizare, RSM

The use of D-optimal design in optimization of wool dyeing with *Juglansregia* bark

In this study, wool fibers were dyed using the Juglansregiabark as a new source of natural dye. Alum was used as mordant. Response surface methodology and D-optimal design were employed to study and optimize the dyeing procedure with the aim of obtaining the maximum color value after dyeing with aqueous extract of Juglansregiabark. The results showed that the color value of the dyed fibers was increased by increasing the dyeing time and temperature and decreased by increasing the dyebath pH value. There was an optimum value of around 6 % owf for mordant concentration. The optimal condition for obtaining the highest color value was as follows: dyebath pH: 6, alum concentration: 6.24 % owf, dyeing temperature: 90°C, and dyeing time: 90 min.

Keywords: mordant, natural dye, wool, optimization, RSM

INTRODUCTION

Natural dyes are known as sustainable and environmentally friendly materials for dyeing and functional finishing of textiles [1]. They can be obtained from vegetable, animal or mineral origin [2]. Several studies have been reported on application of different natural dyes on textile fibers. Barberry tree root, cumin seeds, grape leaves and pomace, red cabbage, milkweed leave, *Achilleapachycephala flowers*, almond shell, pomegranate rinds and wastewater of olive oil production are examples of new sources of natural dyes which have been studied in recent years [3–17]. Despite several advantages associated with the use of natural dyes in dyeing textile goods, there is a great need for optimization of natural dyeing processes to fulfill the equipments of today's industry.

Metal mordants are commonly used in order to increase the uptake and fastness of natural dyes on textile fibers and obtain different shades using a single dye [18]. However, most of metal mordants cause environmental problems as well as health concerns for the consumers [19]. Natural dyeing plants usually posses low color yield and require prolonged time to dye textiles satisfactorily. Several pretreatments like cationization, plasma treatment, enzyme treatment, gamma treatment, and microwave treatment are examples of techniques which have been studied to overcome this drawback [7, 10, 20–24]. To minimize the consumption of energy, dye, mordant, and auxiliaries besides decreasing the required time, while gaining the highest dyebath exhaustion, optimization of the dyeing process is really important [25].

In the traditional method for optimization of processes, experiments are first performed and the measured data is analyzed afterwards. This approach examines one variable at a time and is time and work demanding and the effect of interactions between different factors is not taken into account [26]. In contrast to this, in statistical methods, the experimental design is planned and sets of well selected experiments are performed to get the most informative combination out of the assumed factors with the minimum number of experiments. Response surface methodology (RSM) offers design of experiment (DOE) tools that lead to refined optimization approaches and process performance at minimal cost [27]. D-optimal designs create the optimal set of experiments on the basisof a computer-aided exchange procedure. This method selects the best combination of experimental trials within the limitations provided and provides maximum accuracy in estimating regression coefficients. The optimality criterion results in minimizing the generalized variance of the parameter estimates for a pre-specified model [28–29].

Juglansregia is a tree native to central Asia and can be found in several countries all over the world. Many parts of this tree including green walnuts, shells, seed, bark, and leaves are used in the pharmaceutical and cosmetic industry. The bark of this tree is used as a toothbrush and a dye for coloring the lips for makeup purpose is some parts of south of Iran. It contains several phenolic compounds namely, β-sitosterol, juglone, folic acid, gallic acid, regiolone, and quercetin-3-α-L-arabinoside [30–31].

In this study, the bark of *Juglansregia*tree was chosen as a new source of natural dye for coloration of wool fibers. Four independent factors including mordant concentration, dyebath pH, and temperature besides the dyeing time were selected as the most influencing factors according to preliminary experiments. To find out the optimum conditions for dyeing procedure, D-optimal design was used and the effect of dyeing process factors on the color value of the dyed samples was determined.

EXPERIMENTAL WORK

Materials and methods

Pure wool fabric (plain weave, 250 g/m^2) was purchased from Iran Merinos Textile Company, Iran, and used for the experiments after scouring and drying (1% non-ionic detergent (Triton X-100, Sigma-Aldrich, USA), 50 °C, for 30 min). All other chemicals used in this study were analytical grade reagents obtained from Merck, Germany.

Juglansregia bark was washed with tap water, dried and then powdered. 100 g of powder was used for preparation of 1 liter of the original dye solution. Distilled water was used for this purpose and boiling was continued for 2 h and then the solution was filtered. The concentration of the prepared solution is 10 % W/V.

Experimental Design: The formulation of experiments and statistical analysis of responses were performed using Design Expert software (version 7.0). In this study, the most influencing operating factors of the natural dyeing process were optimized using response surface methodology (RSM) and D-optimal design. The practically feasible ranges for each factor were determined by preliminary studies before designing the experiments. Table 1 presents the corresponding codes besides lower and higher values for each variable.

Table 1

EXPERIMENTAL RANGES OF FACTORS				
Factor	**Name**	**Unit**	**Low level**	**High level**
A	Dyeing pH	-	4	8
B	Mordant concentration	% owf	0	10
C	Dyeing temperature	ºC	50	90
D	Dyeing time	min	30	90

A total number of 25 experiments were proposed by the software. P-value with 95% confidence level was considered for the selection or rejection of the model terms. To analyze the results, ANOVA was employed. Response surfaces were drawn to determine the individual and interactive effects of the process variables on the color value of dyed samples.

Mordanting: The mordanting bath was prepared using the required amount of alum (aluminum potassium sulfate) according to the experimental design and acetic acid was used for adjustment of pH at 5. The liquor to goods ratio (L:G) was 50:1 and the mordanting was done at boil for 1 h.

Dyeing: Dyeing of the samples was performed using 50% owf of the natural dye(L:G= 40:1, pH=4–8). The dyeing was started at 40 °C and the temperature was raised to the final temperature at the rate of 2 °C per minute. Then the samples remained in that condition for the predefined time according to the experimental design, and then rinsed and air dried.

Color value measurements: the reflectance of dyed samples were measured on a Color-eye 7000A spectrophotometer using illuminant D65 and 10° standard observer. Color strength (K/S) of each dyed sample was calculated using kubelka-munk equation for each wavelength ranging between 360–740 nm:

$$K/S = (1 - R)^2 / 2R \tag{1}$$

Where R is the observed reflectance, K – the absorption coefficient and S – the light scattering coefficient. For better comparison of the samples in the full range of the visible spectrum, the sum of color strengths measured at all wavelengths (color value sum or CV_{sum}) was calculated and considered for further analysis.

$$CV_{sum} = \Sigma_{360}^{740} (K/S) \tag{2}$$

RESULTS AND DISCUSSION

Model fitting and statistical analysis

The experimental conditions and color values (CV_{sum}) of the woolen fabric samples dyed with 50 % owf of natural dye are shown in table 2. The data obtained from the colorimetric analysis of the dyed samples were fitted to various models. ANOVA results of fitting different models to the obtained data are shown in table 3. The quadratic model was the most suitable model for describing this process. The analysis of variance was used for measuring up the significance of the effect of the dyeing process variables and their interactions on the CV_{sum} as the response. A P-value less than 0.05 was considered as a sign which confirms that the model and the terms are statistically significant. In case that many insignificant model terms are found, model reduction which means the elimination of the insignificant factors from the model can improve the final model. In this study, model reduction was performed by the software and some insignificant interactions of the variables having P-values higher than 0.05 were eliminated.

Table 2

EXPERIMENTAL DESIGN OF DYEING PROCEDURES AND RESPONSES					
	Factor 1	Factor 2	Factor 3	Factor 4	Response
Run	A: pH	B: Mordant Concentration (% owf)	C: Temperature (ºC)	D: Dyeing time (min)	CV_{sum}
1	4	10	50	30	71.4
2	8	0	50	90	72.2
3	8	0	50	90	61.5
4	4	0	50	30	141.2
5	6	5	90	60	215.5
6	6	5	50	60	146.4
7	8	10	50	90	127.5
8	4	5	50	90	220.4
9	6	10	70	60	85.2
10	4	5	90	30	192.7
11	4	0	90	90	62.2
12	4	10	90	90	172.4
13	88	10	50	90	95.8
14	6	10	90	30	59.6
15	8	0	90	30	133.2
16	8	0	70	30	66.1
17	8	5	90	90	231.6
18	4	0	90	90	142.2
19	6	2.5	70	60	56.8
20	4	0	50	30	92.4
21	8	10	90	30	100.2
22	8	5	50	30	62.9
23	4	5	70	60	179.7
24	8	0	90	60	99.4
25	8	5	70	60	123.8

Table 3

ANOVA RESULTS OF THE FITTING THE EXPERIMENTAL DATA TO VARIOUS MODELS				
Source model	F value	P value Prob > F	R-Squared	
Linear	2.78	0.1320	0.2685	
2FI	3.05	0.1163	0.4920	
Quadratic	0.95	0.5196	0.8469	Suggested
Cubic			0.9217	aliased

Table 4

ANOVA RESULTS OF THE ESTABLISHED MODEL FOR RESPONSES		
Factor	F-Value	P-Value
Model	7.83	0.0003
A: Dyeing pH	5.24	0.0360
B: Mordant concentration	0.65	0.4331
C: Dyeing temperature	7.90	0.0126
D: Dyeing time	9.44	0.0073
AC	4.25	0.0559
BD	10.84	0.0046
B^2	26.32	0.0001
C^2	5.96	0.0267
Lack of Fit	0.73	0.6947

Table 4 shows the analysis of variance (ANOVA) results of the established model for responses. The model *F*-value of 7.83 implies on the significance of the model. When the calculated Value for Prob>*F* related to a certain variable is less than 0.05, itmeans that the corresponding model term is significant at a confidence level of 95%. In this case *A, C, D, BD*, B^2 and C^2 are significant model terms. A high R^2 coefficient confirmed a sensible concurrence between the proposed model and the experimental data.

The "Pred R-Squared" of 0.5245 was in reasonable agreement with the "Adj R-Squared" of 0.6947. "Adeq Precision" shows the extent of divergence in predicted response regarding its associated error or signal to noise ratio and compares the range of predicted values at design points to the average prediction error. A desirable "Adeq Precision" should be higher than 4 and indicates that the mode has been selected suitably [26]. In this case, the ratio of 9.652 impliesthat this model was well selected and can be used forhandling the design space.

Regression analysis was performed on experimental data and the following model equation in terms of coded factors was fitted:

$$CV_{sum} = 136.75 - 16.07A + 6.23B + 19.67C + 25.42D + {} + 17.35AC + 28.00BD - 69.09B^2 + 39.06C^2 \quad (3)$$

The effects of parameters on color value

To compare the effect of four factors on color value of dyed samples, perturbation plot (figure 1) was drawn. This plot shows the effect of changing each factor on CV_{sum} while holding three other factors constant. The reference amounts of the factors to draw the plot are shown on it. A steep slope or curvature in the resulting trace indicates sensitivity of the response to that factor. From the curvature of the plot *B* and *C*, it can be concluded that the response is more sensitive to mordant concentration and dyeing temperature compared with other factors. The lower steep of the pH line shows less sensitivity of the color value to change in this factor at the range investigated in this study.

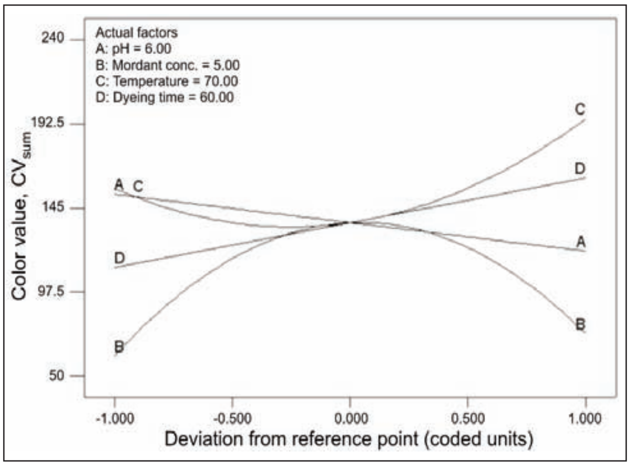

Fig. 1. Perturbation plot for CV_{sum}

Figure 2 shows the individual and simultaneous effects of the dyeing procedure factors on color value of the dyed samples. It can be seen that the addition of alum mordant and increasing its concentration up to 6% owf has increased the color value of the dyed samples. It means that the dye uptake of the mordanted samples has been higher than the non-mordanted sample. Mordanting increases the interaction between the amine groups of wool fibers and hydroxyl and carbonyl groups of juglone as the main colorant present in the extract used for dyeing [32]. When using more than 6% owf of alum, the color strength has been decreased probably due to increasing the physical damage to the wool fibers. The 3D graphs show the simultaneous effects of factors on the response in which the red area indicates the amounts of the factors resulting in the maximum color value. These graphs are useful for establishing response values and operating conditions that are needed.

Figure 3 shows the mechanism of complex formation between the wool protein, aluminum ion, and dye molecule.

Increasing the dyeing time increased the color value due to the higher amount of dye molecules absorbed by the fibers at prolonged time. Increasing the dyebath pH from 4 to 8 has decreased the color value of the dyed samples. Wool fiber gains more positive charges at acidic pH values and the juglone molecules can be better absorbed by positively charged wool fibers at this condition [20, 33]. Increasing the dyeing temperature has increased the color value of the dyed samples due to increasing the exhaustion especially at temperatures higher than 70 °C. This increase in dye-uptake is due to the fibre swelling and breaking the aggregations of dye molecules at higher temperatures which improved the dye diffusion into the wool fiber [20, 34].

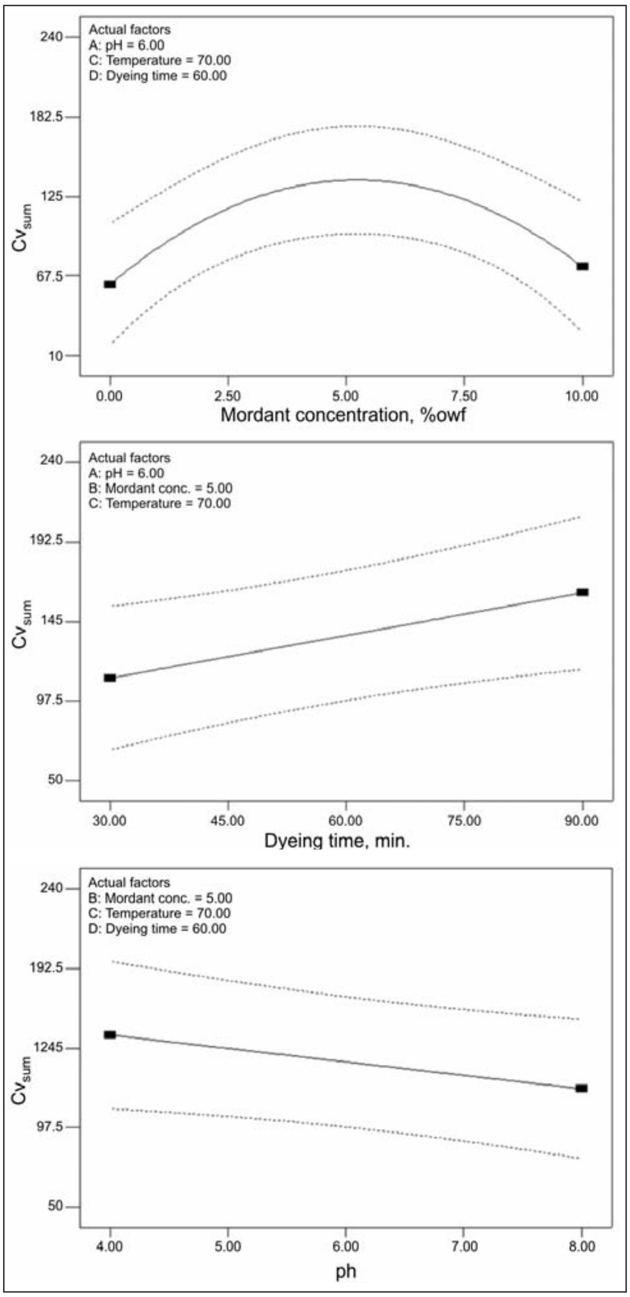

Fig. 2. The individual and simultaneous effects of each factor on color value of dyed samples

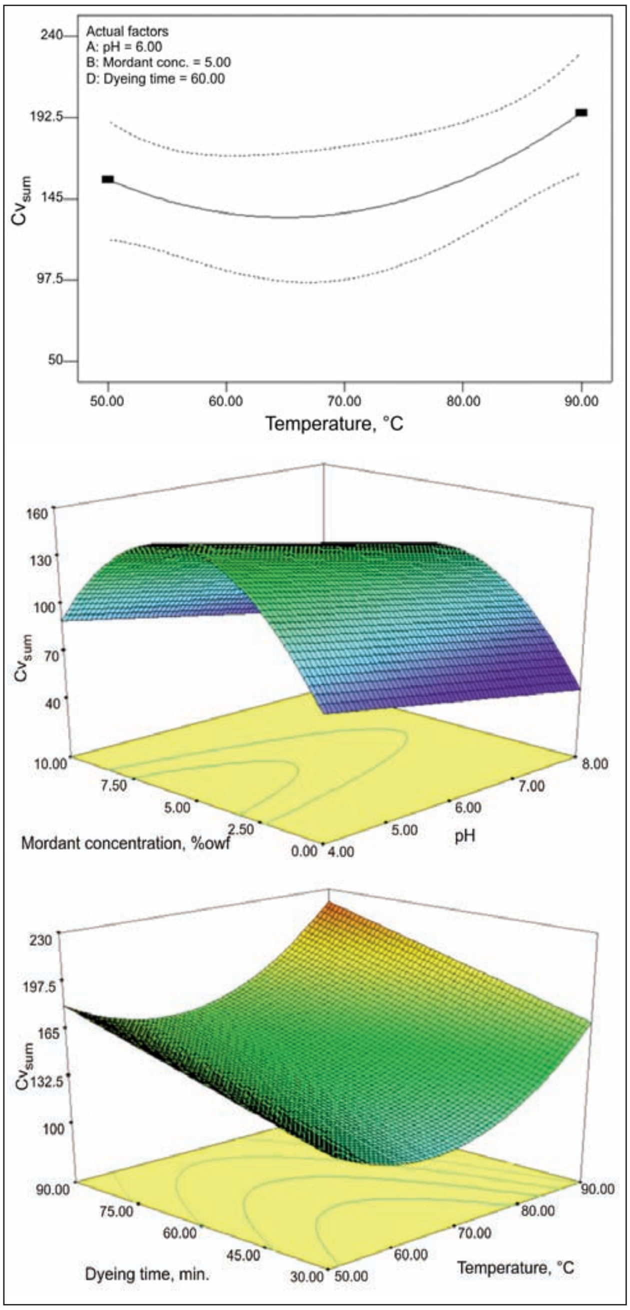

Fig. 2. Continued

Table 5

OPTIMAL CONDITIONS FOR THE DYEINGOF WOOL FIBERS TO OBTAIN MAXIMUM COLOR VALUE						
Dyeing pH	**Mordant concen-tration (%owf)**	**Dyeing temper-ature (ºC)**	**Dyeing time (min)**	**Predict-ed CV_{sum}**	**Experi-mental CV_{sum}**	**Desir-ability**
4	6.24	90	90	223.76	226.93	0.977

Optimization of dyeing process

The maximum color value was taken as the desired response and the optimal conditions for obtaining the maximum CV_{sum} were predicted using the optimization function of Design Expert software. All factors were selected to be "in the range". The optimized conditions are shown in table 5. Good agreement between the predicted CV_{sum} and the experimental value means that the empirical model derived from RSM can be used to adequately describe the relationship between the factors and response in this study.

CONCLUSION

In this study, the aqueous extract of *Juglansregia* bark was used as a natural dye for dyeing of wool. Alum was applied on wool fibers as a mordant using pre-mordanting method. The effects of four independent factors of the dyeing procedure on the color value of the dyed samples were statically studied using response surface methodology. The results showed that the CV_{sum} had the highest sensitivity to mordant concentration and dyeing temperature compared with other factors. Increasing dyeing time and temperature resulted in increasing the CV_{sum}, but the color value was decreased by increasing the dyebath pH, while there was an optimum amount for mordant concentration (around 6% owf) to obtain highest effect on color value. The optimal conditions to obtain the highest color value were derived from statistical data. This natural dyecan be considered as a suitable source of natural dye for coloration of wool fibers.

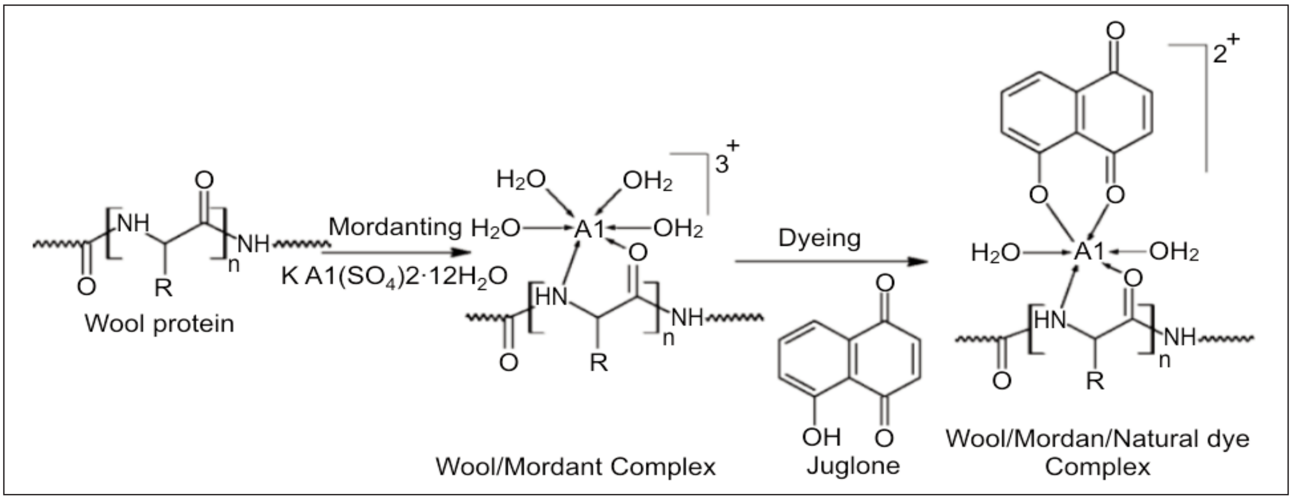

Fig. 3. Mechanism of complex formation between wool, aluminum mordant and juglone dye [32–33]

BIBLIOGRAPHY

[1] Hou, X., Fang, F., Guo, X., Wizi, J., Ma, B., Tao, Y., Yang, Y. *Potential of sorghum husk extracts as a natural functional dye for wool fabrics*. In: ACS Sustainable Chemistry & Engineering, 2017, vol. 5, issue 6, pp. 4589–4597.

[2] Yusuf, M., Shabbir, M., Mohammad, F. *Natural colorants: Historical, processing and sustainable prospects*. In: Natural Products and Bioprospecting, 2017, vol. 7, issue 1, pp. 123–145.

[3] Haji, A., Khajeh Mehrizi, M., Akbarpour, R. *Optimization of β-cyclodextrin grafting on wool fibers improved by plasma treatment and assessment of antibacterial activity of berberine finished fabric*. In: Journal of Inclusion Phenomena and Macrocyclic Chemistry, 2015, vol. 81, issue 1–2, pp. 121–133.

[4] Haji, A., Qavamnia, S.S. *Response surface methodology optimized dyeing of wool with cumin seeds extract improved with plasma treatment*. In: Fibers and Polymers, 2015, vol. 16, issue 1, pp. 46–53.

[5] Haji, A., Qavamnia, S.S., Bizhaem, F.K. *Optimization of oxygen plasma treatment to improve the dyeing of wool with grape leaves*. In: Industria Textila, 2016, vol. 67, issue 4, pp. 244–249.

[6] Baaka, N., Haddar, W., Ben Ticha, M., Amorim, M.T.P., M'Henni, M.F. *Sustainability issues of ultrasonic wool dyeing with grape pomace colourant*. In: Natural Product Research, 2017, pp. 1–8.

[7] Ben Ticha, M., Haddar, W., Meksi, N., Guesmi, A., Mhenni, M.F. *Improving dyeability of modified cotton fabrics by the natural aqueous extract from red cabbage using ultrasonic energy*. In: Carbohydrate Polymers, 2016, vol. 154, issue, pp. 287–295.

[8] Haddar, W., Ben Ticha, M., Meksi, N., Guesmi, A. *Application of anthocyanins as natural dye extracted from Brassica oleracea L. var. capitata f. rubra: dyeing studies of wool and silk fibres* In: Natural Product Research, 2017, pp. 1–9.

[9] Benli, H. *An investigation of dyeability of wool fabric with red cabbage (Brassica oleracea L. var.) extract*. In: Industria Textila, 2017, vol. 68, issue 2, pp. 108–115.

[10] Hussaan, M., Iqbal, N., Adeel, S., Azeem, M., Tariq Javed, M., Raza, A. *Microwave-assisted enhancement of milkweed (Calotropis procera L.) leaves as an eco-friendly source of natural colorants for textile*. In: Environmental Science and Pollution Research, 2017, vol. 24, issue 5, pp. 5089–5094.

[11] Barani, H., Rezaee, K. *Optimization of dyeing process using Achillea pachycephala as a natural dye for wool fibers*. In: Chiang Mai Journal of Science, 2017, vol. 44, issue 4, pp. 1548–1561.

[12] Erdem İşmal, Ö., Yıldırım, L., Özdoğan, E. *Valorisation of almond shell waste in ultrasonic biomordanted dyeing: alternatives to metallic mordants*. In: The Journal of The Textile Institute, 2015, vol. 106, issue 4, pp. 343–353.

[13] Inan, M., Kaya, D.A., Kirici, S. *The effect of dye plant amounts on color and color fastness of wool yarns*. In: Industria Textila, 2014, vol. 65, issue 1, pp. 29–32.

[14] Haji, A. *Improved natural dyeing of cotton by plasma treatment and chitosan coating; optimization by response surface methodology*. In: Cellulose Chemistry and Technology, 2017, vol. 51, issue 9–10, pp. 975–982.

[15] İşmal, Ö.E. *Greener natural dyeing pathway using a by-product of olive oil; prina and biomordants*. In: Fibers and Polymers, 2017, vol. 18, issue 4, pp. 773–785.

[16] Haddar, W., Baaka, N., Meksi, N., Ticha, M., Guesmi, A., Mhenni, M.F. *Use of ultrasonic energy for enhancing the dyeing performances of polyamide fibers with olive vegetable water*. In: Fibers and Polymers, 2015, vol. 16, issue 7, pp. 1506–1511.

[17] Haddar, W., Baaka, N., Meksi, N., Elksibi, I., Farouk Mhenni, M. *Optimization of an ecofriendly dyeing process using the wastewater of the olive oil industry as natural dyes for acrylic fibres*. In: Journal of Cleaner Production, 2014, vol. 66, issue 1, pp. 546–554.

[18] Büyükakinci, B.Y. *Investigation of dyeing methods on wool fabrics with hibiscus and its antibacterial efficiency*. In: Industria Textila, 2017, vol. 68, issue 2, pp. 103–107.

[19] Haddar, W., Ben Ticha, M., Guesmi, A., Khoffi, F., Durand, B. *A novel approach for a natural dyeing process of cotton fabric with Hibiscus mutabilis (Gulzuba): process development and optimization using statistical analysis*. In: Journal of Cleaner Production, 2014, vol. 68, issue, pp. 114–120.

[20] Sajed, T., Haji, A., Khajeh Mehrizi, M., Nasiri Boroumand, M., *Modification of wool protein fiber with plasma and dendrimer: Effects on dyeing with cochineal*. In: International Journal of Biological Macromolecules, 2017, https://doi.org/10.1016/j.ijbiomac.2017.09.038.

[21] Molakarimi, M., Khajeh Mehrizi, M., Haji, A. *Effect of plasma treatment and grafting of β-cyclodextrin on color properties of wool fabric dyed with Shrimp shell extract*. In: The Journal of The Textile Institute, 2016, vol. 107, issue 10, pp. 1314–1321.

[22] Vankar, P. S., Shukla, D., Wijayapala, S. *Innovative Silk dyeing using Enzyme and Rubia cordifolia extract at room temperature*. In: Pigment & Resin Technology, 2017, vol. 46, issue 4, p. null.

[23] Zahid, M., Bhatti, I.A., Adeel, S., Saba, S. *Modification of cotton fabric for textile dyeing: industrial mercerization versus gamma irradiation*. In: The Journal of The Textile Institute, 2017, vol. 108, issue 2, pp. 287–292.

[24] Stanculescu, I., Chirila, L., Popescu, A., Cutrubinis, M. *Gamma pre-irradiation effects on natural dyeing performances of proteinic blended yarns*. In: Environmental Engineering and Management Journal, 2017, vol. 16, issue 4, pp. 913–920.

[25] Nasirizadeh, N., Dehghanizadeh, H., Yazdanshenas, M.E., Moghadam, M.R., Karimi, A. *Optimization of wool dyeing with rutin as natural dye by central composite design method*. In: Industrial Crops and Products, 2012, vol. 40, issue Supplement C, pp. 361–366.

[26] Rahbar, R.S., Haji, A. *Use of D-optimal design to model and the analysis of the effect of the draw ratio on some physical properties of hot multistage drawn nylon 6 fibers*. In: Journal of Applied Polymer Science, 2013, vol. 130, issue 2, pp. 1337–1344.

[27] Whitcomb, P.J., Anderson, M.J., *RSM simplified: optimizing processes using response surface methods for design of experiments*, CRC press. Boca Raton, USA, 2004.

[28] Triefenbach, F. *Design of experiments: the D-optimal approach and its implementation as a computer algorithm*, Department of Computing Science, Umea University, Umea, Sweden, 2008.

[29] Barani, H., Broumand, M.N., Haji, A., Kazemipur, M. *Optimization of dyeing wool fibers procedure with isatis tinctoria by response surface methodology*. In: Journal of Natural Fibers, 2012, vol. 9, issue 2, pp. 73–86.

[30] Zakavi, F., Golpasand Hagh, L., Daraeighadikolaei, A., Farajzadeh Sheikh, A., Daraeighadikolaei, A., Leilavi Shooshtari, Z. *Antibacterial effect of juglans regia bark against oral pathologic bacteria*. In: International Journal of Dentistry, 2013, vol. 2013, issue, pp. 1–5.

[31] Chaieb, K., Kouidhi, B., Slama, R.B.E.N., Fdhila, K., Zmantar, T., Bakhrouf, A. *Cytotoxicity, Antibacterial, antioxidant, and antibiofilm properties of Tunisian juglans regia bark extract*. In: Journal of Herbs, Spices & Medicinal Plants, 2013, vol. 19, issue 2, pp. 168–179.

[32] Bukhari, M.N., Shahid-ul-Islam, Shabbir, M., Rather, L.J., Shahid, M., Singh, U., Khan, M.A., Mohammad, F. *Dyeing studies and fastness properties of brown naphtoquinone colorant extracted from Juglans regia L on natural protein fiber using different metal salt mordants*. In: Textiles and Clothing Sustainability, 2017, vol. 3, issue 1, pp. 1–9.

[33] Ali Khan, M., Shahid Ul, I., Mohammad, F. *Extraction of natural dye from walnut bark and its dyeing properties on wool yarn*. In: Journal of Natural Fibers, 2016, vol. 13, issue 4, pp. 458–469.

[34] Kamel, M.M., El-Shishtawy, R.M., Yussef, B.M., Mashaly, H. *Ultrasonic assisted dyeing: III. Dyeing of wool with lac as a natural dye*. In: Dyes and Pigments, 2005, vol. 65, issue 2, pp. 103–110.

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A body measurements and sensory evaluation-based classification of lower body shapes for developing customized pants design

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REZUMAT – ABSTRACT

Clasificarea măsurătorilor corpului şi evaluarea senzorială a formelor părții inferioare a corpului pentru dezvoltarea modelelor personalizate de pantaloni

În lucrarea de față, se aplică o metodă aproximativă de clasificare bazată pe un set fuzzy pentru a identifica formele părții inferioare a corpului pentru o populație țintă, cu scopul de a dezvolta modelul personalizat al pantalonilor. A fost selectat un grup de designeri pentru a identifica dimensiunile cheie şi indicatorii formelor părții inferioare a corpului în ceea ce priveşte modelele de pantaloni de damă. A fost propus un algoritm de clasificare, care utilizează funcții triunghiulare şi trapezoidale fuzzy pentru transformarea indicilor datelor relevante în cinci seturi fuzzy, considerate descriptori lingvistici. S-au definit gradul de importanță şi gradul de similaritate pentru a rezolva conflictele diferiților indicatori. Au fost selectate aleatoriu 125 corpuri umane din populația țintă, au fost măsurate valorile dimensiunilor cheie prin intermediul unui sistem 3D de scanare corporală şi au fost calculați indicatorii importanți ai formelor corpului. Ulterior, au fost create o serie de tabele de decizie şi au fost împărțite formele diferitelor poziții ale părții inferioare a corpului în cinci clase, utilizând metoda setului aproximativ. Rezultatele clasificării au fost validate utilizând o procedură de evaluare senzorială. Rezultatele obținute au contribuit în mod eficient la crearea unor dimensiuni de îmbrăcăminte noi adaptate la o populație țintă şi la realizarea conceptului de personalizare în masă, prin dezvoltarea unor stiluri de îmbrăcăminte personalizate.

Cuvinte-cheie: model de pantaloni, clasificarea formelor părții inferioare a corpului, tehnici fuzzy, seturi aproximative, grad de importanță, grad de similaritate, evaluare senzorială

A body measurements and sensory evaluation-based classification of lower body shapes for developing customized pants design

In this paper, a fuzzy rough set-based classification method is applied to identify lower body shapes of a target population for developing customized pants design. First, a group of designers is selected for identifying the key dimensions and lower body shape indices related to women pants design. On the basis of this, we propose a classification algorithm, which uses triangle and trapezoid fuzzy membership functions for transforming the indices of the relevant data into five fuzzy sets, regarded as linguistic descriptors. An importance degree and a similarity degree are defined to solve conflicts of different indices. Next, we randomly select 125 human bodies in the target population and measure the key dimension values by means of a 3D body scanning system and then compute important body shape indices. Then, we set up a number of decision tables and respectively divide the shapes of various lower body positions into five classes by using the rough set method. The classification results have been validated by using a sensory evaluation procedure. The obtained results will effectively help to set up new garment sizes adapted to a target population and realize the concept of mass customization by developing personalized or customized garment styles.

Keywords: pants design; lower body shape classification; fuzzy techniques; rough sets; importance degree; similarity degree; sensory evaluation

INTRODUCTION

Body shape analysis has become especially significant for satisfying the personalized requirements of a target population in garment design and mass customization. By classifying the population, ready-to-wear products such as pants, can be designed and produced more accurately and individually.

At present, information about body sizes and shapes is obtained from body measurements. During an anthropometric survey, many different body dimensions can be measured on each individual, resulting in thousands of data points, which should be further analysed to identify the significant dimensions that can be used to divide the target population into clusters each having similar body dimensions. These significant body dimensions are known as key dimensions [1]. The first scientific study of body measurements by using key dimensions for garment design was presented in 1941 by O'Brien and Shelton [1]. They used a bivariate distribution technique to develop sizes according to bust and hip girth. Later, Otieno classified children's body shapes according to height and bust girth for upper body garments or hip girth for lower body garments [2]. Hsu applied a bust-to-waist ratio approach to develop body measurement charts for female clothing [3].

In practice, different body positions have different morphological features. Therefore, the existing classification criteria are often rough and the fitting level to a specific body shape is not high enough. In addition, the existing body classifications are mainly realized by using classical statistical methods [4–9]. However, in garment design, designers usually describe body shapes using linguistic terms such as fat or thin, tall or short, etc. The classical methods often lead to unsatisfactory results since they cannot be used to process human perception effectively.

Since these linguistic terms reflect designer's conventional expressionsdescribing their imprecise and vague perceptions, fuzzy techniques are very suitable for dealing with this situation [10–12]. On the basis of this, we tried to classify body shapes by using fuzzy clustering method and obtained dynamitic cluster results, butthese results are sometimes quite different from the real situation in garment design [13]. In practice, experienced designer's knowledge and perception, usually leading to very relevant body shape classification results in terms of garment styles and other design elements, have never been exploited in the existing clustering algorithms.

Rough set theory [14], proposed by Pawlak, has become a well-established mechanism for uncertainty management in a wide variety of applications. Particularly, rough set have astrong ability of knowledge classification. Thus, we propose a fuzzy rough set-based method for pants design in order to accurately classify the shapes of various body positions of a given population since the classification of body shapes should be sensitive to the overall morphological features of the target population. Sensory data on human body shape perception, provided by design experts have also been integrated into the proposed classification method.

EXPERIMENTAL WORK

In garment design, relative values between body measurements, i.e. differences and ratios, are generally more significant than direct measurements for classifying body shapes. Therefore, it is necessary to identify characteristic indices of body shapes according to the differences and ratios between key dimensions.

Identification to key dimensions of lower body

As we know, there are thousands of data points related to the lower body in 3D anthropometric data. Only some key dimensions which are significant related to a specific population and a special garment can be selected. The measurements related to the lower body include the vertical dimensions, such as Stature (*S*), Waist Height (*WH*), Crotch Height (*CH*), Knee Height (*KH*), Thigh Length (*TL*), and the horizontal dimensions, such as Waist Girth (*W*), Hip Girth (*H*), Abdomen Girth (*A*), Thigh Girth (*T*), Calf Girth (*C*), Knee Girth (*K*) [15].

As known by designers, Knee Height (*KH*), Thigh Length (*TL*) and Knee Girth (*K*) are more relevant to garment pattern construction and less concerned by garment design and body shape[16]. In this context, we only consider eight measurements as key dimensions including Stature, Waist Height, Crotch Height, Waist Girth, Hip Girth, Abdomen Girth, Thigh Girth and Calf Girth, which constitute a measuring vector for a specific human body in this study, for the subject of pants design, which can be defined as: **MEASURE**=(*S*, *WH*, *CH*, *W*, *H*, *A*, *T*, *C*).

The characteristic indices of the lower body shape

The lower body shapes, generally described by fashion designers using waist shape (*WS*), hip shape (*HS*), abdomen shape (*AS*), leg length (*LL*), thigh shape (*TS*) and calf shape (*CS*). As we only focus on the large and small of various body positions in our research, 15 frequently-used body shape indices are regarded as the characteristic indices of the relevant body shapes as follows.

(1) An waist shape index: $\boldsymbol{WS} = W/S$
Three hip shape indices: $HS_1 = H–W$, $HS_2 = H/W$, $HS_3 = H/S$

(2) They can constitute an index vector on hip shape: $\boldsymbol{HS} = (HS_1, HS_2, HS_3)$

(3) Three abdomen shape indices: $AS_1 = A–W$, $AS_2 = A/W$, $AS_3 = A/S$
They can constitute an index vector on abdomen shape: $\boldsymbol{AS} = (AS_1, AS_2, AS_3)$

(4) Two leg length indices: $LL_1 = CH/S$, $LL_2 = WH/S$
They can constitute an index vector on leg length: $\boldsymbol{LL} = (LL_1, LL_2)$

(5) Three thigh shape indices: $TS_1 = T/W$, $TS_2 = T/H$, $TS_3 = T/S$
They can constitute an index vector on thigh shape: $\boldsymbol{TS} = (TS_1, TS_2, TS_3)$

(6) Three calf shape indices: $CS_1 = C/W$, $CS_2 = C/H$, $CS_3 = C/S$
They can constitute an index vector on calf shape: $\boldsymbol{CS} = (CS_1, CS_2, CS_3)$

The increase of each index from small to large can describe the change of the shape of the relevant body position from small to large. These characteristic indices directly derived from the corresponding body measurements, can effectively describe the human body shape and permit to perform further studies such as body shape classification.

Sensory evaluation of body shapes

The concept of sensory evaluation was firstly presented by Amerine in food industry, which is applied to obtain the consumers' subjective experience on food products [17]. Nowadays, it has been expanded asa general scientific discipline that uses human senses to evaluate a specific object [18].

In this study, according to the visual perception of designers on body shapes, each body position can be divided into five sensory classes: "Very Small (*VS*)", "Small (*S*)", "Middle (*M*)", "Large (*L*)", "Very

Large (VL)".Therefore, the evaluation scores can be defined using a linguistic level of {VS, S, M, L, VL}.

Fuzzy classification model to various lower body positions

Since there is only one index on waist shape, the characteristic index of the waist shape is just the classification index. However, to each other body position, not all indices can express its shape well. Therefore, we need to identify the most suitable classification index in order to model the classification of body shapes.

The importance degree proposed by rough set theory is a suitable parameter to identify classification index since it only depends on a data-based decision table without prior knowledge. In a decision table, the importance degree of a condition attribute {a} related to the decision D is defined by formula (1) [19].

$$\sigma(a) = \frac{|\mathrm{pos}_C(D)| - |\mathrm{pos}_{C-\{a\}}(D)|}{U} \tag{1}$$

where U is a set of body shapes, C – a set of condition attributes, D = {d} expresses the decision attribute, $\mathrm{pos}_C(D)$ – the C positive domain of D, $|\cdot|$ expresses the cardinality of a set.

First, we need to set up a discrete decision table for each lower body position by taking the related characteristic indices as condition attributes and the sensory data as decision attribute. Since the body shapes described by linguistic terms are more significant in garment design, which can be fully expressed by fuzzy set, all the characteristic index values should be fuzzified by proper fuzzy sets.

(1) Fuzzification of characteristic indices

Let $b = \{b_1, b_2, \ldots, b_n\}$ be the set of human bodies and the j-th characteristic index value of b_i be x_{ij} (i=1,…,n; j=1,…,q). All data should be normalized to interval [0,1] for avoiding the effect of units. Here we normalize x_{ij} to $\bar{x}_{ij}$ by using max-min method [20] as follows.

$$\bar{x}_{ij} = \frac{x_{ij} - \min}{\max\text{-}\min} \quad (i=1,\ldots,n;\ j=1,\ldots,q) \tag{2}$$

Each normalized index value $\bar{x}_{ij}$ (i=1,…,n; j=1,…,q) can be transformed as five fuzzy sets expressed by five evaluation levels (scores) {VS, S, M, L, VL}. For this purpose, we denote the following five numerical values.

$$X_{j1} = \min_{1\le i\le n}\{\bar{x}_{ij}\},\ X_{j3} = \operatorname{median}_{1\le i\le n}\{\bar{x}_{ij}\},\ X_{j5} = \max_{1\le i\le n}\{\bar{x}_{ij}\},$$
$$X_{j2} = \frac{X_{j1} + X_{j3}}{2},\ X_{j4} = \frac{X_{j3} + X_{j5}}{2} \tag{3}$$

Using these five values, the five fuzzy sets can be expressed respectively by $\tilde{C}_1$, $\tilde{C}_2$, $\tilde{C}_3$, $\tilde{C}_4$, $\tilde{C}_5$, each having a triangle or trapezoidal membership function as figure1.

Denote $\mu_{ij}^{(k)}$ as the membership function of the index value $\bar{x}_{ij}$ (i=1,…,n; j=1,…,q) to the fuzzy set $\tilde{C}_k$ (k=1,2,...,5). $\bar{x}_{ij}$ is fuzzified to $\tilde{C}_{k^*}$ if $\mu_{ij}^{(k^*)} = \max_{1\le k\le 5}\{\mu_{ij}^{(k)}\}$.

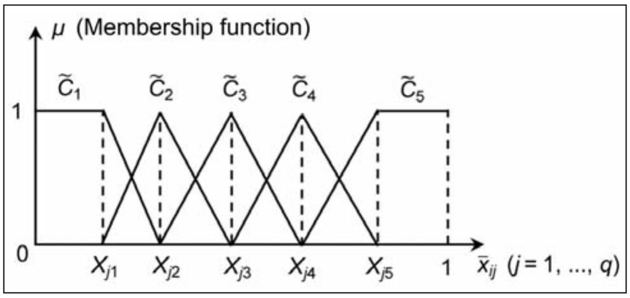

Fig. 1. Fuzzy membership functions of body shape indices

Thus, each index value are expressed by a fuzzy set $\tilde{C}_k$ (k=1,2,…,5).

(2) Classification algorithm

(a) If all index levels of a body position are consistent, any index can be taken as the classification index.

(b) If the index levels of a body position are inconsistent, the classification index is determined according to the importance degree or similarity degree.

(b1) If the importance degrees of various indices are different and their differences are greater than a threshold th, the index with highest importance degree is taken as the classification index.

(b2) If there are at least two indices with the highest importance degree or the differences of the first two importance degrees are less than th, we consider the similarity degrees between a specific body shape and the centers (mean of data) of the various index levels of each body position.

Let $I = (x_1, x_2, \ldots, x_t)$ be an index vector of a specific body position b. b can expresses hip shape, abdomen shape, leg length, thigh shape or calf shape.

Let $\bar{I}^{(j)} = (x_1^{(j)}, x_2^{(j)}, \ldots, x_t^{(j)})$ be a mean vector of the j-th index level, where $\bar{x}_i^{(j)}$ is the mean of all samples data on the j-th index level of the i-th index, with i = 1, 2, …, t; j = 1, 2, …, 5.

The similarity degree of I to $\bar{I}^{(j)}$ is defined by

$$\mathrm{Sim}\left(I, \bar{I}^{(j)}\right) = \exp\left(-\left\|I - \bar{I}^{(j)}\right\|\right) \tag{4}$$

where "$\|\cdot\|$" expresses the Euclidean distance of two vectors.

If all the similarity degrees of I to various levels are different, the shape of body position will be classified to the class with the maximum similarity degree. But if the similarity degrees of $I$to at least two levels are highest, we need to invite experts to make a judgment.

On this basis, we get the decision rules using logic expression as follows.

Assume $(y_1, y_2, \ldots, y_t)$ be a group of characteristic indices of b, and the index level of y_i is denoted as level(y_i) with i = 1, 2, …, t. Let k, j^* express the fuzzified value of body shape, with k, j^* = 1, 2, …, 5.

(r1) $\forall\ i$, level$(y_i) = k \rightarrow b$ is "k".

(r2) $i \neq j \wedge \text{level}(y_i) \neq \text{level}(y_j) \wedge \sigma(y_i) =$
$= \max_{1\le i\le t}\{\sigma(y_i)\} \rightarrow b$ is "level(y_i)".

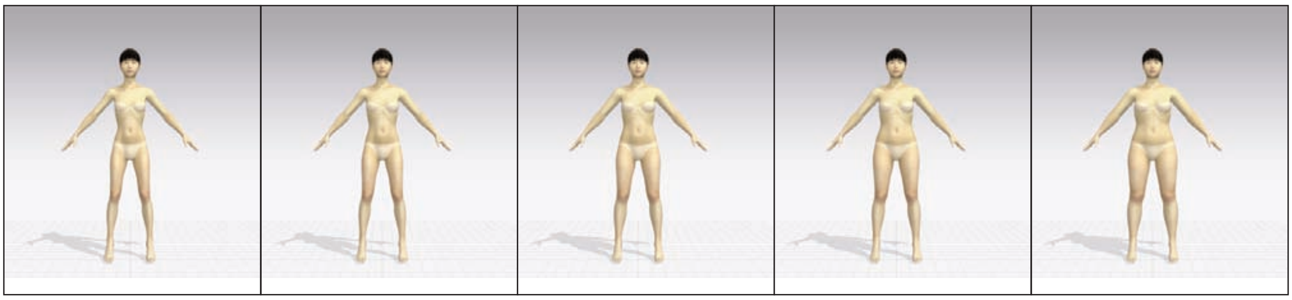

Fig. 2. The five virtual human bodies whose hip shapes from "very small" to "very large":
a – *VS* (69.9 cm); *b* – *S* (75.1 cm); *c* – *M* (84.0 cm); *d* – *L* (95.0 cm); *e* – *VL* (99.0 cm)

(r3) $i \neq j \wedge \text{level}\,(y_i) \neq \text{level}\,(y_i) \wedge \sigma\,(y_i) =$
$= \sigma\,(y_i) \wedge \text{Sim}\,\left(I, \bar{I}^{(j)}\right) = \max\left\{\text{Sim}\,\left(I, \bar{I}^{(j)}\right)\right\} \to b$ is "*j*".

According to our algorithm, any lower body shape can be expressed by a 6-dimension body shape vector (*WS*, *HS*, *AS*, *LL*, *TS*, *CS*) and there are 5^6 kinds of potential body shapes. In practice, body shapes of a specific population are only a fraction of them by analyzing the features of human bodies.

Classification of target population

We randomly select 125 young women of Central China from 18–25 as samples to set up our model. Two experiments are carried out including 3D body scanning and the sensory evaluation on body shapes. Each experimental result is discretized as a fuzzy set $\tilde{C}_k$ ($k = 1,2,\ldots,5$) by previous proposed method.

According to the previous discussion, we first set up five decision tables on other five body positions except waist shape and then compute the importance degrees of various indices as table 1.

According to the proposed classification algorithm, we get the following conclusions (here $th = 0.01$).

(1) $\sigma(HS_3) > \sigma(HS_2) > \sigma(HS_1)$ and $|\sigma(HS_3) - \sigma(HS_2)| >$ > 0.01, so the classification index of hip shape is HS_3.

(2) $\sigma(AS_2) > \sigma(AS_3) > \sigma(AS_1)$ and $|\sigma(AS_3) - \sigma(AS_2)| >$ > 0.01, so the classification index of abdomen shape is AS_2.

(3) As $\sigma(LL_1) > \sigma(LL_2)$ and $|\sigma(LL_1) - \sigma(LL_2)| > 0.01$, the classification index of leg length is LL_1.

(4) $\sigma(TS_2) > \sigma(TS_1) > \sigma(TS_3)$ but $|\sigma(TS_2) - \sigma(TS_1)| <$ < 0.01, so the classification index of thigh shape needs to be determined by similarity degree according to the index value vector of thigh shape of each specific human body (It will be discussed in the following example).

(5) $\sigma(CS_2) > \sigma(CS_1) > \sigma(CS_3)$ and $|\sigma(CS_3) - \sigma(CS_2)| >$ > 0.01, so the classification index of calf shape is CS_2.

Based on above conclusions, we can classify all body shapes in samples and ultimately these samples are divided into 103 classes according to the shapes of 6 lower body positions. It can be seen that there are not too much same body shapes in the samples. Taking the hip shapes classification of the women with 160 cm stature as an example, the human body and the Hip Girths corresponding to the center (the mean of the classification index) of each class can be displayed virtually as figure 2.

Table 1

IMPORTANCE DEGREE OF BODY SHAPE INDICES

Index	Importance degree	Index	Importance degree
HS_1	0.0847	LL_2	0.8729
HS_2	0.2288	TS_1	0.5593
HS_3	0.6017	TS_2	0.5678
AS_1	0.1864	TS_3	0.3305
AS_2	0.4153	CS_1	0.4661
AS_3	0.3390	CS_2	0.8390
LL_1	0.9746	CS_3	0.1695

RESULTS AND DISCUSSION

Validation of model

In our research, since the classification results of body shapes will be used in garment design, they have to fit the perception criteria of designers. Therefore, validity of the model is determined by whether the model output and the perception criteria of designers are consistent or compatible.

The distribution graphs of the model output and perception criterion on the shapes of various body parts are shown in figure 3.

From these distribution graphs, it seems that two distributions are rather close. However, the intuitional analysis is imprecise, which requires further validated by quantized method.

Relative Entropy (Cross Entropy) is introduced to this study, which is often used to measure the degree of approximation between two probability distributions. Suppose that two probability distribution functions are $p(x)$ and $q(x)$ respectively, Relative Entropy (Cross Entropy) [21] of $p(x)$ and $q(x)$ is defined by

$$D(p,q) = E_p\left[\log \frac{p(x)}{q(x)}\right] = \sum_{x \in \chi} p(x) \log \frac{p(x)}{q(x)} \qquad (6)$$

Generally, $D(p,q) \neq D(q,p)$. Therefore, we propose an Improved Cross Entropy by the mean of $D(p,q)$ and $D(q,p)$ as follows.

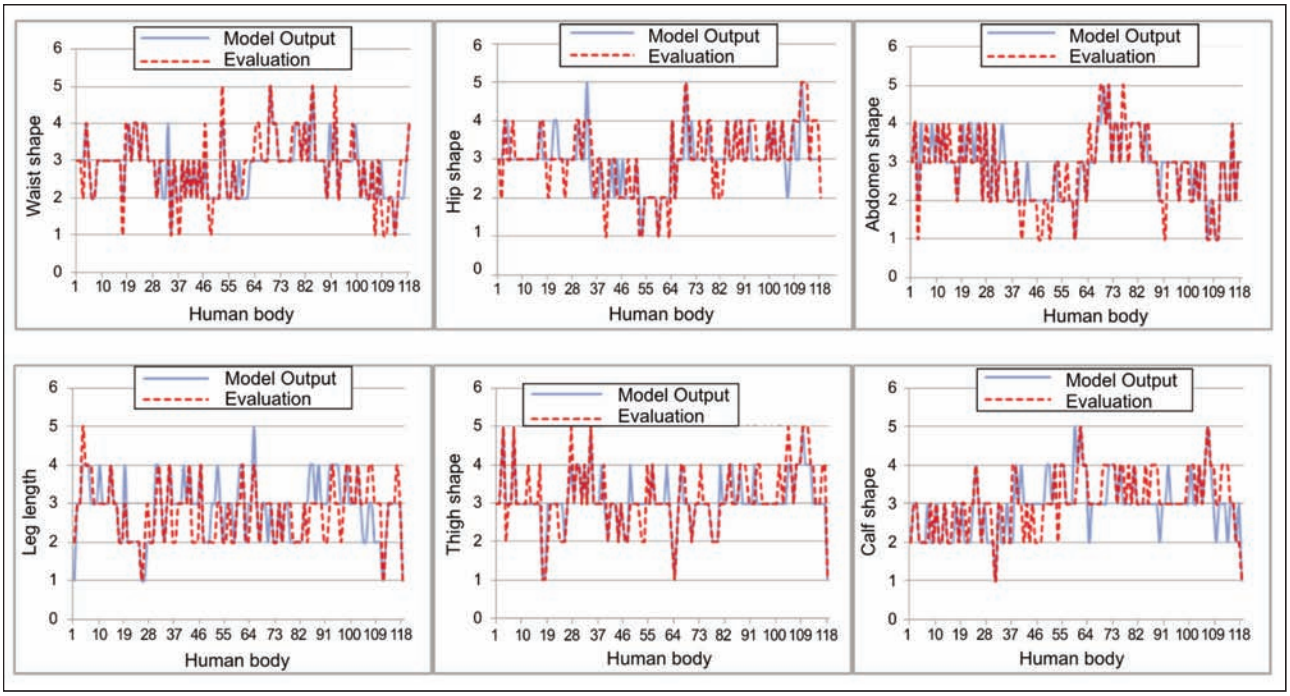

Fig. 3. Comparison between predict results of model and perception criterion on body shapes classification. 1, 2, 3, 4 and 5 expresses respectively *VS*, *S*, *M*, *L* and *VL*

$$ID(p,q) = \frac{1}{2}\left[D(p,q) + D(q,p)\right] = \tag{7}$$
$$= \frac{1}{2}\left[\sum_{x\in\chi} p(x)\log\frac{p(x)}{q(x)} + \sum_{x\in\chi} q(x)\log\frac{q(x)}{p(x)}\right]$$

The smaller cross entropy is, the closer $p(x)$ and $q(x)$ is.

In our research, $\chi = \{VS, S, M, L, VL\}$, $p(x)$ is the frequency distribution function of model output and $q(x)$ – the frequency distribution function of perception criteria of experts. The cross entropies related to the shape of each body position is listed in table 2.

Table 2

IMPROVED CROSS ENTROPYOF EACH BODY POSITION					
Body part	**Cross entropy**	**Body part**	**Cross entropy**	**Body part**	**Cross entropy**
Waist	0.0548	Abdomen	0.0417	Thigh	0.0563
Hip	0.0435	Leg	0.0220	Calf	0.0258

It is clear that all of these results are less than 0.1, which shows that the output of this model is rather close to the perception criterion. According to the above discussions, we can believe that the proposed model has a good classification capability on body shapes.

An illustrate example

We give an example for classifying a real human body by using the proposed model. We randomly select a human body from the target population, whose 3D body scanning result is presented in figure 4. Themeasuring vector by 3D body scanning is as follows.

The measuring vector is measure = (166.5, 105, 76.3, 66, 91.6, 77.6, 55, 32.7) and all units are "cm". Thus, ***WS*** = 0.3962 and the related index vectors are computed as follows.

HS = (25.6, 1.3879, 0.5498), ***AS*** = (11.6, 1.1758, 0.4658), ***LL*** = (0.4580, 0.6303), ***TS*** = (0.8333, 0.6004, 0.3301), ***CS*** = (0.4955, 0.3570, 0.1963).

They can be normalized as follows

normal (***WS***) = 0.4759, normal (***HS***) = (0.5972, 0.5270, 0.5038), normal (***AS***) = (0.6360,0.5190,0.4950), normal (***LL***) = (0.4907, 0.5183), normal (***TS***) = (0.5603, 0.5332, 0.5373), normal (***CS***) = (0.5008, 0.4731, 0.4776).

After fuzzy operation, we obtain the discretized index vectors as:

fuzzified (***WS***) = $\tilde{C}_2$, fuzzified (***HS***) = $(\tilde{C}_4, \tilde{C}_4, \tilde{C}_3)$, fuzzified (***AS***) = $(\tilde{C}_4, \tilde{C}_4, \tilde{C}_3)$, fuzzified (***LL***) = $(\tilde{C}_3, \tilde{C}_4)$, fuzzified (***TS***) = $(\tilde{C}_5, \tilde{C}_4, \tilde{C}_4)$, fuzzified (***CS***) = $(\tilde{C}_3, \tilde{C}_2, \tilde{C}_2)$.

According to the proposed classification principle, we can learn the shapes of various body positions of the woman as follows: the waist shape is "$\tilde{C}_2$", the Hip shape is "$\tilde{C}_3$", the abdomen shape is "$\tilde{C}_4$", the leg length is "$\tilde{C}_3$", and the calf shape is "$\tilde{C}_2$".

The thigh shape needs to be identified by using similarity degree. We only need to consider two indices TS_1 and TS_2, on which the mean vectors of various index levels is as follows

$$\bar{I}^{(1)} = (0.4078, 0.4480),\quad \bar{I}^{(2)} = (0.4664, 0.4822),$$
$$\bar{I}^{(3)} = (0.5026, 0.5049),\quad \bar{I}^{(4)} = (0.5426, 0.5139),$$
$$\bar{I}^{(5)} = (0.5476, 0.5490).$$

And the index vector of thigh shape and I = (0.5603, 0.5332). Thus,

$\mathrm{Sim}(I, \bar{I}^{(1)}) = 0.8397$, $\mathrm{Sim}(I, \bar{I}^{(2)}) = 0.8986$, $\mathrm{Sim}(I, \bar{I}^{(3)}) =$ $= 0.9377$, $\mathrm{Sim}(I, \bar{I}^{(4)}) = 09742$, $\mathrm{Sim}(I, \bar{I}^{(5)}) = 0.9799$.

Fig. 4. The 3D body scanning image of the human body to be analyzed

As a result, $\mathrm{Sim}(I, \bar{I}^{(5)}) = \max_j \{\mathrm{Sim}(I, \bar{I}^{(j)})\}$.
Therefore, the thigh shape of this woman is "$\tilde{C}_5$".
Thus, the lower body shape of this woman is (WS(*S*), HS(*M*), AS(*L*), LL(*M*), TS(*VL*), CS(*S*)).

CONCLUSIONS

Body shape classification permits to divide the whole human bodies into different clusters, which has similar body dimensions. It is significant for garment size identification and customized garment design, and strongly related to the distribution of body shapes in a target population. This paper proposes a classification algorithm for classifying the lower body shapes of the target population into different classes. By following the principle of garment design process, the proposed algorithm utilizes the exploitation of designer's perception on body shapes instead of specific numerical data on body measurements. In this context, fuzzy techniques seem to be relevant tools for modeling and processing uncertain linguistic evaluation data describing body shapes. In the proposed algorithm, the key index data related to the linguistic descriptors, provided by designers, are first fuzzified. Based on these fuzzy data and sensory data, we set up a decision table for the lower body shape classification. In this decision table, all the key indices constitute the condition attribute sets while the sensory data is regarded as decision attribute. Next, we gather all similar body shapes into one cluster using equivalence relations established by rough sets. In fact, rough sets theory has shown in various applications with its exceptional abilities for classification of decision tables. For solving conflicts between index values, we compute the importance degrees of attributes and select the index with the biggest importance degree as the classification index if their importance degrees are different. The similarity degree of a body shape to the center of each class of body shapes will be considered if the importance degrees of the indices are equal and the index with maximum similarity degree will be regarded as the classification index. Ultimately, the shape of every body position of a female's lower body is divided into five classes by using rough set method: very small (*VS*), small (*S*), medium (*M*), large (*L*), very large (*VL*), which are fit for human's perceptional recognition to body shapes. According to the validation of the model and an illustrative example, we believe the proposed algorithm is effective.

In practice, the proposed classification idea can be also applied to the classification of upper body shapes and other populations such as south-Africa people.

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BIBLIOGRAPHY

[1] Zakaria, N. *Body shape analysis and identification of key dimensions for apparel sizing system*s, In: Anthropometry Apparel Sizing & Design, 2014, pp. 95–119.

[2] Otieno, R.B. and Fairhurst, C. *The development of new clothing size charts for female kenyan children, Part I: Using anthropometric data to create size charts,* In: Journal of the Textile Institute, 2000, vol. 2, issue 91, pp. 143–152.

[3] Hsu, C. *Applying a bust-to-waist girth ratio approach to develop body measurement charts for improving female clothing manufacture,* In: Journal of the Chinese Institute of Industrial Engineers. 2008, vol. 3, issue 25, pp. 215–222.

[4] Tsunawake, N., et al. *Classification of body shape of male athletes by factor analysis,* In: US National Library of Medicine National Institutes of Health, 1994, vol. 6, issue 13, pp. 383–392.

[5] Takabu, H. *Analysis and classification of human body shape aimed applying to clothing design,* In: Journal of Home Economics of Japan, 2008, vol. 1, issue 59, pp. 687–6977.

[6] Hasler, N., et al. *A Statistical model of human pose and body shape,* In: Computer Graphics Forum, 2009, vol. 2, issue 28, pp. 337–346.

[7] Choi, Y.L. and Yun, J.N. *Classification of upper lateral body shapes for the apparel industry,* In: Human Factors & Ergonomics in Manufacturing, 2010. vol. 5, issue 20, pp. 378–390.

[8] Huang, C.Y. *Study on classification of body shape and size grading on young women of Quanzhou District*, In: Advanced Materials Research. 2014, vol. 1, issue 989–994, pp. 5319–5322.

[9] Olaru, S., Filipescu, E. and Niculescu, C. *Morphological indicators for characterization of women thorax and basin shape, for garment design in customised system*, In: Industria Textila, 2011. 62, 6, pp. 289–295.

[10] Zadeh, L.A. *Fuzzy sets,* In: Information & Control, 1965, vol. 3, issue 8, pp. 338–353.

[11] Chen, Y. *From body measurements to human perception of body shapes: Modeling using intelligent techniques,* In: Computational Intelligence, 2010, vol. 4, issue 1, pp. 1084–1089.

[12] Wang, L.C., et al. *Intelligent fashion recommender system: Fuzzy logic in personalized garment design,* In: Human-Machine Systems (IEEE Transactions), 2015, vol. 1, issue 45, pp. 95–109.

[13] Dong, M., Zeng, X, and Koehl, L. *Dynamic fuzzy clustering of lower body shapes for developing personalized pants design*, In: Conference on Uncertainty Modelling in Knowledge Engineering and Decision Making, 2016, vol. 10, issue 1, pp. 898–904.

[14] Pawlak, Z. *Rough Sets: Theoretical aspects of reasoning about data*, Kluwer Academic Publishers, 2010.

[15] Ben Azouz, Z., et al. *Characterizing human shape variation using 3D anthropometric data,*In: The Visual Computer, 2006, vol. 5, issue 22, pp. 302–314.

[16] Olaru, S., et al. *Morphological assessment of human body for clothing patterns design*, In: Industria Textila, 2013. vol. 5, issue 64, pp. 254–259.

[17] Amerine, M.A., Pangborn, R.M., and Roessler, E.B. *Principles of sensory evaluation of food,* In: Principles of Sensory Evaluation of Food, 1965, vol. 1, issue 1, pp. 159–176.

[18] Wikipedia contributors, *Sensory analysis*. In: Wikipedia, 2016.

[19] Pawlak, Z. *Rough set theory and its applications to data analysis.* In: Cybernetics & Systems, 1998, vol. 29, issue 29, pp. 661–688.

[20] Uragun, B. and Rajan, R. *Developing an appropriate data normalization method,* In: IEEE/ACM Transactions on Computational Biology & Bioinformatics, 2011, vol. 2, issue 2, pp. 195–199.

[21] Zhang, M. *Information theory and statistics,* In: Wiley, 1959, vol. 288, issue 54, pp. 301.

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Effect of elastane linear density on compression pressure of V-shaped compression socks

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REZUMAT – ABSTRACT

Efectul densităţii liniare a elastanului asupra presiunii de compresie a şosetelor de compresie cu fire de vanisare

Scopul acestui studiu a fost de a evalua efectul densităţii liniare a materialelor din elastan asupra valorilor de compresie laterale (gleznă şi gambă) a unor noi variante de şosete de compresie (cu fire de vanisare). În acest scop, au fost utilizate trei tipuri de fire: fire de bază (MY), fire de vanisare (PY) şi fire de căpuşeală (IY). Fiecare fir conţine material elastan drept miez cu densităţi liniare variabile. Reglajele maşinii au fost optimizate pentru a se obţine şosete de compresie speciale cu fire de vanisare, în funcţie de dimensiunea fixă a piciorului. Toate firele au fost instalate simultan şi evaluate pentru impactul lor asupra valorii presiunii de compresie la diferite segmente de picior. În total, au fost dezvoltate şi cuantificate 18 probe de şosete pentru exercitarea presiunii utilizând dispozitivul MST MKIV, un dispozitiv de monitorizare a presiunii Salzmann. Toate probele au fost analizate utilizând software-ul ANOVA în MINTAB 16. În final, numai două probe de şosete au fost finalizate, obţinându-se valori de exercitare a presiunii de 21 mmHg şi 23 mmHg, cu un nivel de compresie graduală de 76% şi 74%, simultan.

Cuvinte-cheie: compresie, densitate lineară, elastan, şosete cu fire de vanisare, fir filat cu miez, fir acoperit, fir dublu acoperit

Effect of elastane linear density on compression pressure of V-shaped compression socks

The aim of this study was to evaluate the effect of elastane material linear densities on lateral compression values (ankle and calf) in newly designed shape (V-shape) compression socks. For this purpose, three types of yarns: main yarn (MY), plating yarn (PY) and inlaid yarn (IY) were used. Each yarn contains elastane material as core with varying linear densities. Firstly, Machine adjustments were optimized to achieve special V-shaped compression socks according to fix leg size. All the yarns were installed simultaneously and evaluated for their impact on compression pressure value at different segments of leg. Total eighteen socks samples were developed and quantified for pressure exertion using MST MKIV, Salzmann pressure monitoring device. All samples were analyzed using ANOVA in MINTAB 16 software. Consequently, only two socks samples finalized acquiring pressure exertion values of 21 mmHg and 23 mmHg with graduation percentage of 76% and 74% simultaneously.

Keywords: compression, linear density, elastane, V-shaped socks, core spun yarn, air covered yarn, double covered yarn

INTRODUCTION

Compression socks are highly recommended textile garment for pressure exertion on the lower part of leg [1]. Mechanism of action is a varying degree of compression to different segments of the leg, with the highest pressure at the ankle, must gradually decrease in upward direction. These types of socks are highly recommended for treatment of chronic venous diseased patients [2]. Physical and constructional properties of compression socks are of most importance because its properties directly relate to the type of patient and intensity of the disease. The extent of compression that a patient can easily manage depends on stage (limb size and shape) of venous disease and his activities (mobility, age). Apart from above considerations, compression socks must exert maximum pressure at the ankle, which should decrease to the upper part of the limb. These compression socks must acquire both comfortable and appropriate level of compression. Medical compression devices (MCD) are considered being more effective in preventing and reducing edema if it is capable to exert interface pressure on the gaiter area up to 40 mmHg [3].

As per international classification of pressure exertion intensity, it is classified as CCL1 (light) up to 20 mm Hg; CCLII (moderate) 20–30 mmHg and CCLIII firm compression (30–40 mmHg). These levels of pressure exertion are recommended medically to treat circulatory and vascular medical conditions as well for tired, sore, swollen, or aching legs [3–6].

Theoretically, the amount of pressure in the circumferential direction of leg depends on the radius (R) of leg and reversal force T (N).

According to Laplace's Law [5]

$$P\,(\mathrm{Pa}) = \frac{T\,(\mathrm{N})}{R\,(\mathrm{cm})} \tag{1}$$

Where P = Pressure, T = Reversal fabric tension, R = Radius of leg.

For the pressure measurement on a patient's leg, circumference of the ankle and calf portion is required (1), so the equation (1) can be modified to

$$P\,(\mathrm{Pa}) = \frac{T\,(\mathrm{N}) \times 2\pi}{C\,(\mathrm{cm})} \tag{2}$$

Where P = Pressure, T = Reversal fabric tension, C = Circumference of leg
or

$$P\,(\mathrm{Pa}) = \frac{T\,(\mathrm{N}) \times 2}{W\,(\mathrm{cm})} \tag{3}$$

Where P = Pressure, T = Reversal fabric tension, W = width of socks.

Using the Laplace's formula, it is evident that the operating pressure should be greatest at the point of the lowest girth area (ankle) and have the slightest pressure at the point of maximum girth area (calf). Apart from the position of the leg, the circumference (thin or thick) of the leg also needs optimum or lower pressure on cutaneous and subcutaneous skin layers which satisfies the Laplace's Law [7].

Hui and Ng (2001) attempted to design a theoretical model for prediction of interface pressure between the skin and garment using multilayer fabric tubes. All tubes have different tensile properties and compare its validation. Designed model is given below.

$$P = \frac{\in 2\pi\,(E1h1 + E2h2)}{C} \tag{4}$$

Where = axial strain, E = modulus of elasticity, h = thickness of textile tube.

This model was experimentally verified by measuring the tensile properties of elastic fabric exhibit breaking load capacity up to 60 kg and breaking extension capacity in both directions (warp and weft)up to 360% using an Instron tensile strength machine (model 1026) under zero load, using the cut-strip test. Specimen size selected 5 × 15 cm, gauge length 10 cm, specimen extended 5–60% lengthways at 5% intervals, extended rate 200 mm/min; clamp width 5 cm (flat faces), tension load cell was 5 Kg. The tension force (Kgf) was recorded for each 10% stretch to calculate the stress (N/m^2) of a fabric specimen. In order to obtain a stable stress-strain curve for an elastic fabric, we ran a few cycles of extension and relaxation before the test. Elastic tubes pressure was measured using oxford MKII pressure monitoring device at fix locations of cylindrical tubes under the elastic fabric. This pressure values were compared with the modulus properties were measured under ASTM D2256-97.Theoretical and actual measurements were compared and found the values to be very closer [8].

Hui and Ng (2001) attempted to design pressure model for the human leg interface pressure by the compression garment given below. They selected warp knitted elastic fabric and compared these pressure values using Oxford MKII pressure monitoring device between human body skin and donned garment

$$\mathrm{Re} = \frac{1}{1 + \dfrac{2\pi\,\mathrm{EI}\,(\mathrm{CF})}{\mathrm{C\,human} + \mathrm{F}}} \tag{5}$$

They concluded that compression factor is very important parameter. Instead of using a trial and error approach, this proposed pressure model could help therapists to make pressure garments more effectively and efficiently [9].

Normally, compression socks are recommended for the patients who have stabilized leg circumference and no longer edema. In this situation the socks will correspond effectively to a minor increase in leg circumference. It is also recommended for optimal compression, these would be donned early in the morning when edema is reduced.

A few of the studies are there in which proper development of socks has been done, but mostly researcher had worked on manufactured socks.

Liu et al. (2005) investigated the effect of different material properties and fabric structure characteristics of graduated compression stockings (GCS) on the Skin Pressure Distributions. For this study, they selected eight different commercially available stockings comprised of polyamide and elastane material of varying composition. They concluded that structural characteristics and material properties of stockings were not even along the length of the leg except gradual variation of compression pressure from ankle to thigh which significantly influenced the corresponding skin pressure gradient distributions [10].

Partsch et al. (2006) studied interface pressure and stiffness of ready-made compression stockings. In this study the interface pressure of several medical compression stockings was measured on 12 legs from six employees (5 women, 1 man) having their mean ages 43.2 years (range, 20 to 61). Calf-length compression stockings of the European classes I, II, III and the two class I socks over each other were applied on 12 legs. Interface pressure was measured using MST tester using wooden leg models. It was concluded that in vivo and in vitro measurement, an increase in stiffness causes the increase in compression pressure. The highest values are found for two class I stockings applied over each other [8].

Gaieda et al. (2006) used the combination of main yarn as well as inlaid yarn having Lycra in core wrapped by polyamide. The objective was to obtain compression pressure up to 30 mm of Hg, but observed no significant results except 20 mm of Hg was achieved [11].

Maleki et al. (2011) investigated the effect of different stitch lengths (0.22 cm, 0.25 cm, 0.27 cm, 0.29 cm and 0.32 cm) and repeated usages on two different types (plain and interlock) of knitted structures. They concluded that stitch length is significant parameter, as it increases; there occurs a decrease in pressure and vice versa. While interlock structured fabrics exhibit higher stitch length so display more pressure reduction [12].

Dalbey et al. (2011) had patented their work using core spun yarn having sheath of Polyester as a main

yarn and double covered Nylon yarn on Lycra core as inlaid yarn achieved maximum compression up to 40 mm of Hg [13].
Troynikova O et al. (2013) studied the influence of material properties and garment composition on the pressure generated by sport compression garments using two differently structured knitted fabrics with different physical properties and elastic performance. These samples were tested using compression pressure measuring device MST MK IV. The researchers concluded that different material composition of fabric assemblies influenced the pressure delivery of garment [14].
Normally, socks (weft knitted) are composed of three yarns types defined body yarn, plated yarn and inlaid yarn. Body yarns as in direct contact with skin provide different feels to wearer. Inlaid yarns used are single covered or double covered yarns that run through the heads of loop form by body yarn. It controls stretch, optimum pressure, intimate contact and grip over the leg portion and avoids the sliding of the socks. The loop-forming yarns like body yarn (spun/filament) and plated yarn (air covered) form the loops together. Inlaid yarn (double covered yarn) is integrated into each loop of every course [13–16].
Various studies exits in which different fiber/yarn types (varying elastane linear densities and compositions) different types of spun/core spun yarns of different linear densities, different kind of inlaid yarn, varying tension by increasing or decreasing ultra feeder yarn tensions into knitting machine and different fabric structures (manufactured and ready-made), different sizes and shapes of the substrate (cylindrical tube or wooden leg) had been used to exert maximum pressure at the ankle and optimum graduation [2, 4, 14, 16–18]. But there is no study in which the effect elastane material linear densities used in all the three socks components body yarn, plated yarn and inlaid yarn is studied in specially designed V-shaped socks.
In normal compression socks graduation percentage varies from 60% to 80% of the total compression pressure at the ankle. The most important property required in graduated compression socks is to attain the highest sub-garment compression pressure at ankle according to European classification of compression pressure. The graduation compression pressure means gradually lowering of pressure along the length of the leg towards the calf. If does not reduces while moving upward may cause blood clotting and swelling of inner walls of the veins. The intensity of compression pressure suggested for the patients depends on the type, history and intensity of the disease. The severe is the disease, the higher compression pressure suggested for the patient to prevent the recurrence of lymph edema.
The objective of this study is to investigate the influence main yarn (MY), plating yarn (PY), and inlaid yarn (IY) on compression pressure at ankle, calf and graduation percentage between 70 to 80%.

MATERIALS AND METHOD

Materials (yarns)

Compression socks are comprised of three yarns types i.e. main, plated and inlaid abbreviated as main yarn (MY), plating yarn (PY) and Inlaid yarn (IY).
Main/Body yarn: Three types of main yarns (core Spun) were selected abbreviated as (MY1*, MY2* & MY3*) as shown figure 1. All have same Overall linear density i.e. 29.52 tex but different elastane material linear densities i.e. 4.4 tex, 7.77 tex, 11.7 tex respectively. Here *MY1: 4.4 tex Lycra-29.52/1 tex core spun cotton 96%, *MY2: 7.8 tex Lycra-29.52/1 tex core spun cotton 93% and *MY3: 11.7 tex Lycra-29.52/1 tex core spun cotton 90%. Testing results of main yarn are given below in table 1.
Inlaid yarn: Three types of double covered Nylon filament yarn were selected as shown in figure 2 can be abbreviated as (IY1*, IY2*& IY3*). Each type contains elastane yarn of different linear densities i.e. 13.3 tex, 15.5 tex and 33 tex but fixed sheath yarn linear density i.e. 15.55 tex/24f/1. Here *IY1: 13.3 tex-15.55/ 24f/1 tex Raw White Nylon DCV 17%, *IY2: 15.50 tex-15.55/24f/1 tex Raw White Nylon DCV 19% and *IY3: 33.0 tex-15.55/24f/1 tex Raw White

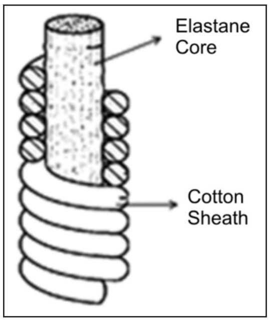

Fig. 1. Front view of Core Spun yarn [12]

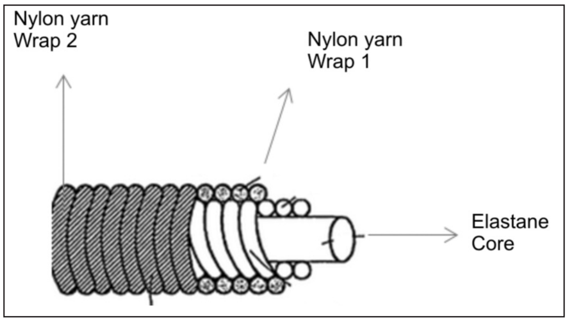

Fig. 2. Double covered Nylon Filament yarn [19]

Table 1

Sr. no	Main yarn codes	Yarn linear density (tex)		Draw ratio	Elastane composition (%)
		Resultant	Elastane		
1	MYELD1	29.52	4.4	3.48	4.32
2	MYELD2	29.52	7.8	3.64	7.22
3	MYELD3	29.52	11.7	3.65	10.83

MY: Main Yarn, E: Elastane, LD: Linear Density

Table 2

Sr. no	Inlaid yarn codes	Yarn linear density (tex)			Draw ratio	Elastane composition (%)
		DCV Resultant	Nylon	Elastane		
1	IYELD1	20.22	15.55	13.3	1.63	17.27
2	IYELD2	21.11	15.55	15.5	1.85	18.6
3	IYELD3	27.33	15.55	33	1.56	34.08

IY: Inlaid Main, E: Elastane, LD: Linear Density

Table 3

Sr. no	Plating yarn codes	Yarn linear density (tex)			Elastane	
		ACV	Sheath	Elastane	Draw ratio (%)	Composition (%)
1	PYED1	9.11	7.77	2.2	3.2	8
2	PYED2	9.44	7.77	2.2	2	12.5

PY: Plated Yarn, E: Elastane, D: Draft

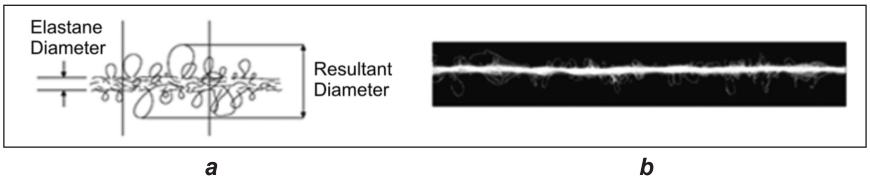

Fig. 3. Side view of ACV yarn:
a – resultant and elastane diameter; *b* – scanned plated air covered yarn [20]

Nylon DCV 34% (DCV: Double covered). Testing results of inlaid yarns are given in the table 3.

Plating yarn: Two types of nylon air covered yarns were selected abbreviated as (PY1* & PY2*) as shown in (figure 3) having different draft values (2% & 3.2%) were selected. Here *PY1: 2.2 tex Lycra-7.77 tex/24 filamnet/1 Raw White Nylon ACV 8%, *PY2: 2.2 tex Lycra-7.77 tex/24 filament/1 Raw White Nylon ACV 12.5% [ACV: air covered]. Testing results of plating yarn are given in table 2.

Method

Machine specifications

Technical specifications of selected conventional machine are given below in table 4.

Optimization of machine adjustments

In this section, we adjusted the conventional socks knitting machine to 2 steps special settings to achieve desired V-shape ribbed socks. Step (I): Gradient change in the Degree of needles for main and plating yarns Step (II): Varying graduation motor speed for Inlaid yarn as shown in figure 4 and figure 5. Total 322 courses were inserted in the rib portion (1×1) of each socks sample.

Main yarn and plating yarn insertion were divided into three zones of varying degree of needles. In each zone, 108 courses were inserted with decreasing degree of needles from the calf portion (400 degree) to ankle portion (100 degree). A zone with the lowest degree (100) of needles was introduced at the ankle portion as required lowest loop height to exert highest pressure and highest degree (400) at calf portion is required to attain lower pressure at calf than ankle. Inlaid yarn insertion was divided into seven zones and controlled by varying graduation motor speed from 600 rpm to 1400 rpm from calf to ankle. In seven zones, each zone contains 46 courses with reduction of constant speed of 200 rpm of graduation motor at each zone out of seven.

After optimization of machine adjustments, V shape socks were manufactured at above mentioned setting, but with changing types of yarns.

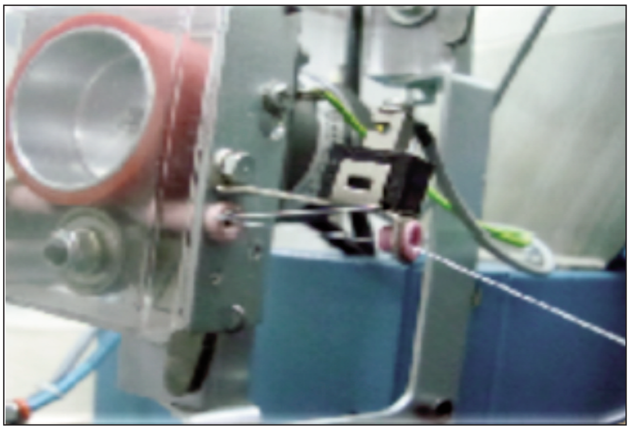

Fig. 4. Schematic diagram of elastic motor

Table 4

Model	Company	Cylinder	Gauge	Diameter	Speed	Feeder	Needles
L462 2005	Lonati	Single	12	3.75″	250 rpm	2	168

Preparation of V shaped socks

Three yarns (main, plating and Inlaid) were loaded on socks knitting machine at above mentioned adjustments. Desired V- shape socks are shown in figure 5.

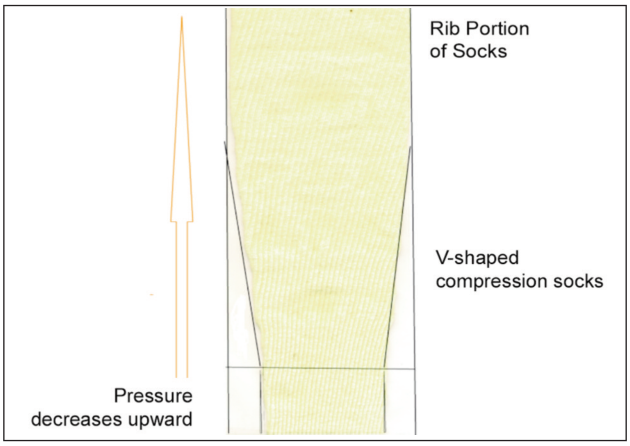

Fig. 5. V-shaped compression socks prepared on conventional knitting machine

Physical specifications of socks samples and wooden leg

Widths (diameter) of all the socks samples were measured at the ankle (6.5 cm to 8.5 cm) and a calf portion (9 cm to 10.5). This difference in widths is due to machine adjustments and varying linear densities of elastane materials. Width measurements of the socks samples and wooden leg are given below in table 5.

Table 5

Sr. no.	Socks width	Unit (cm)	Wooden leg width (cm)
1	Ankle	6.5–8.5	8.28
2	Calf	9–10.5	12.42

Pressure measurement of V-shaped socks

Compression pressure of all the socks samples was measured using MST MK IV SALZMANN compression tester under standard test method of ENV 12718 as shown in figure 6. The device consists of a thin plastic sleeve (4 cm wide, 0.5 mm thick), with four to six paired electrical contact points. The measuring points are B, ankle; B1, gaiter area; C, largest calf circumference; and D, below knee as shown in figure 6, connected to an air pump and a pressure transducer. This probe is placed between the leg and the compression device. The air pump at rate of 1 mmHg/sec inflates the wrapper until the contacts open. The contact of compression garment to wooden leg is diminished when the inner pressure exerted by the air is just above external pressure due to the compression device. When the contact opens, the transducer reads the pressure at each measuring point and the pressure value displayed digitally with 1-mmHg resolution [1].

Fig. 6. Schematic diagram of MST MKIV Salzmann pressure-measurement device

Compression pressure values at ankle portion, calf portion and graduation percentage (*G* %) was calculated. *G* % is a very important factor keep in mind as helpful to regulate the blood flow. Liu et al. (2005) studied that the compression socks should exert maximum pressure at ankle decreasing to upward (hip side) [4]. This gradient change in pressure, generate the pressure between capillaries and enhance the rate of blood flow through the veins [1].
Graduation percentage (*G* %) from ankle to calf portion is calculated using formula

$$\text{Graduation percentage } (G\ \%) = (P^c \div P^a) \times 100 \quad (6)$$

P^c = Pressure at calf portion, P^a = Pressure at ankle portion (16).

RESULTS AND DISCUSSION

Compression properties

The experimental variables are: main yarn elastane linear density (MYELD), plating yarn elastane draft (PYED) and in-laid yarn elastane linear density (IYELD). Table 6 shows compression pressure values of developed socks at the ankle, at the calf and the percentage graduation.

Effect of elastane linear densities (main and Inlaid) and draft (plated) at ankle

Effect of elastane linear densities used in all socks samples at the ankle was analyzed first using ANOVA tool (Statistical software MINITAB). In this case to construe whether the parameters are significant or not, p values are examined. As known, if the ‘p’ value of a parameter is greater than 0.05 ($p > 0.05$), the parameter will not be statistically significant. ANOVA values of compression pressure at ankle are shown in table 7.
The analysis of variance data shown in table 4 indicates that the p-value of effect of main yarn elastane linear density (MYELD) and inlaid yarn elastane linear density (IYELD) is below 0.05 which depict the significant influence of input variables on compression pressure at ankle while the impact of plating yarn elastane draft on compression pressure at ankle is non-significant ($p > 0.005$).
Figure 7 and figure 8 portray the trend of main yarn elastane linear density, inlaid yarn elastane linear density and plating yarn elastane draft on exertion pressure at ankle.

Table 6

Sr. no.	Code detail	MYELD [dtex]	IYELD [dtex]	PYED [ratio]	Pressure at ankle (P_a) [mmHg]	Pressure at calf (P_c) [mmHg]	Graduation [%]
1	M1I1P1	44	133	2	13	11	84.61
2	M1I1P2	44	133	3.2	15	14	93.3
3	M1I2P1	44	155	2	13	11	84.6
4	M1I2P2	44	155	3.2	13	14	107.69
5	M1I3P1	44	330	2	21	16	76.19
6	M1I3P2	44	330	3.2	23	17	73.91
7	M2I1P1	78	133	2	16	14	87.5
8	M2I1P2	78	133	3.2	18	16	88.8
9	M2I2P1	78	155	2	17	15	88.23
10	M2I2P2	78	155	3.2	18	17	94.44
11	M2I3P1	78	330	2	26	22	91.66
12	M2I3P2	78	330	3.2	24	22	91.66
13	M3I1P1	117	133	2	17	16	94.11
14	M3I1P2	117	133	3.2	16	16	100
15	M3I2P1	117	155	2	19	16	84.21
16	M3I2P2	117	155	3.2	17	18	105.88
17	M3I3P1	117	330	2	22	22	100
18	M3I3P2	117	330	3.2	23	22	95.65

M1, M2 & M3 = Main Yarns, I1, I2 & I3: Inlaid yarns, P1 & P2 = Plated Yarns

Table 7

Source	DF	Adj. SS	Adj. MS	F-value	P-value
Model	13	243.114	18.7011	24.57	0.004
Linear	5	230.112	46.0223	60.46	0.001
MYELD	2	40.148	20.0741	26.37	*0.005
ILELD	2	189.561	94.7807	124.51	*0.000
PYED	1	0.402	0.4020	0.53	0.508
Error	4	3.045	0.7612		
Total	17	246.159			

* Significant variables

Figure 7 and figure 8 demonstrate that as the linear density of the elastane material of the main yarn increases from 44 detx to 78 detx, increase in

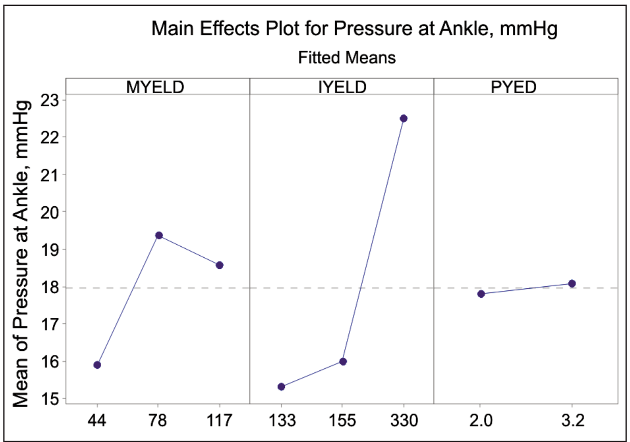

Fig. 7. Main yarn elastane linear density (MYELD), Plating yarn elastane Draft (PYED) and inlaid yarn elastane linear density (IYELD) Vs compression pressure (mm Hg) at ankle

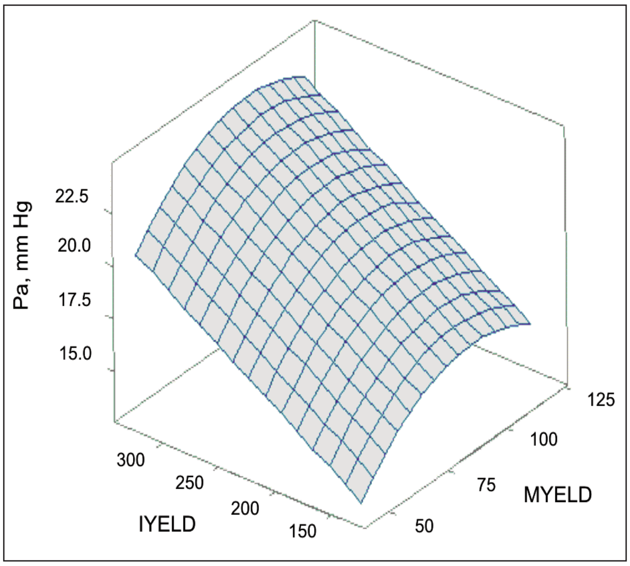

Fig. 8. Surface plot of pressure at ankle(mm Hg) Vs Main yarn elastane linear density (MYELD), and inlaid yarn elastane linear density (IYELD)

compression pressure from 16 mm Hg to 19 mm Hg at ankle takes place. But as the linear density of elastane material increases more from 78 detx to 117 dtex, a non-significant decrease in compression pressure at ankle from 19 mm Hg to 18 mm Hg takes place. Increase in compression pressure from 16 mm Hg to 19 mm Hg by increasing the linear density of the elastane material is due to increase in the contraction of the socks. The fabric density at ankle increases as the linear density of the elastane material increases, which gradually reduces loop length and air spaces while increasing the stiffness and compactness of the fabric. As the linear density of the main yarn elastane material increases more 78 dtex to 177 dtex, there observed a slight decrease in compression pressure. The reason of decrease in compression pressure is due to additional compactness/least air spaces in knitted fabric which do not allow the fabric to contract more than the size of the wooden leg minimum girth area (ankle) ultimately reducing the compression pressure at ankle. The wooden dummy used in this study has width/circumference (cm) 8.28/26 cm while the prepared socks has the width range from 6 cm ~7.5 cm that when worn to leg size it is stretched to extent according to circumference of the leg.

Inlaid yarn is the yarn which moves transversely along each course of main yarn loops while missing the one loop of the wale (rib construction 1×1). It is evident from the figure 7 and figure 8 that as the linear density of the elastane material increases from 133 dtex to 155 dtex, a slight increase in compression pressure from 15 mm Hg to 16 mm Hg takes place but as the linear density of the inlaid yarn increases from 155 dtex to 330 dtex, incredible increase in compression pressure from 16 mm Hg to 23 mm Hg takes place.

Diana et al. (2013) reported that the linear pressure depends on the linear density of the PU core material and insertion density of the inlaid yarn. She also reported that extensibility of the socks can be controlled (transversely and longitudinally) by the increasing or decreasing insertion density of the inlaid yarn according to requirement [23].

$$\text{Pressure at Ankle (mm Hg)} = 2.03 + 0.3094\ \text{MYELD} + 0.03681\ \text{IYELD} - 0.001693\ \text{MYELD} * \text{MYELD} \quad (7)$$

R-Sq. for the regression equation (1) is 93% which signifies that 93 % change in compression pressure at ankle can be explained by the terms included in the equation.

Effect of elastane linear densities (main and inlaid) and draft (plated) at calf

Analysis of developed compression socks at calf was made using statistical software called as MINITAB. For the statistical importance of the experimental factors, analysis of variance (ANOVA) tool was applied. In order to construe whether the parameters were significant or not, p values were examined. As known, if the ‘p’ value of a parameter is greater than 0.05 ($p > 0.05$), the parameter will not be statistically significant.

The analysis of variance data shown in table 8 indicates that the p-value of main yarn elastane linear density (MYELD) and inlaid yarn elastane linear density (IYELD) and plating yarn elastane draft is below 0.05 which depict the significant influence of input variables on the compression pressure at calf.

Figure 9, 10 and 11 represents the impact of main yarn elastane linear density, inlaid yarn elastane linear density and plating yarn elastane draft on the exertion pressure at the calf.

Main yarn is usually in contact with the skin and forms the wales and courses in the socks, which transversely and longitudinally affect the socks size and compactness of loops in knitted fabric. Figures 9,

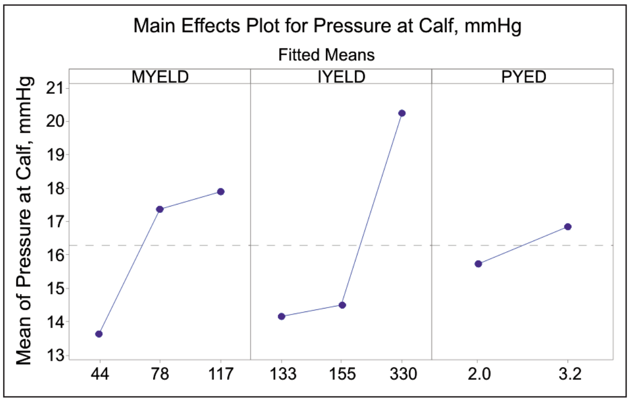

Fig. 9. Main effect plot of main yarn elastane linear density (MYELD), Plating yarn elastane draft (PYED) and inlaid yarn elastane linear density (IYELD) Vs compression pressure (mm Hg) at calf

Table 8

Source	DF	Adj. SS	Adj. MS	F-value	P-value
Model	13	224.590	17.2762	25.32	0.003
Linear	5	211.697	42.3394	62.05	0.001
MYELD	2	65.091	32.5453	47.69	*0.002
ILELD	2	141.006	70.5032	103.32	*0.000
PYED	1	5.600	5.6001	8.21	*0.046
Error	4	0.6824	0.6824		
Total	17	227.320			

*Significant variables

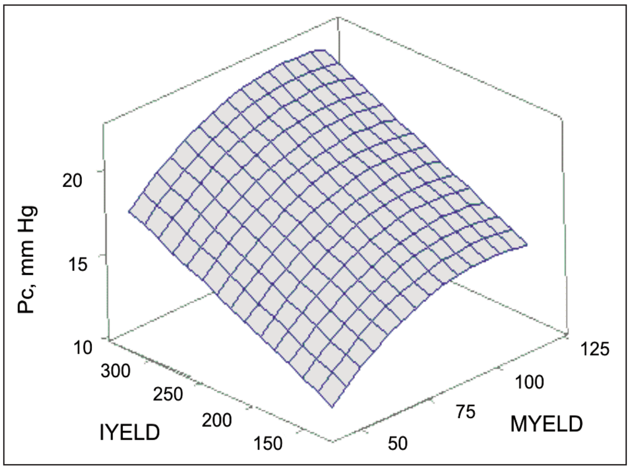

Fig. 10. Surface plot of main yarn elastane linear density (MYELD), and Inlaid yarn elastane linear density (IYELD) Vs compression pressure (mm Hg) at calf

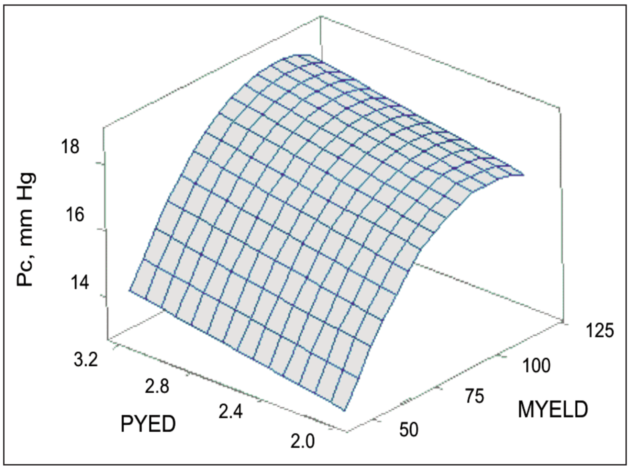

Fig. 11. Surface plot of main yarn elastane linear density (MYELD) and plating yarn elastane (PYED) draft Vs compression pressure (mm Hg) at calf

10 and 11 show that as the linear density of the elastane material of main yarn increases from 44 dtex to 78 dtex, the incredible increase in compression pressure from 13 mm Hg to 17 mm Hg takes place. As the linear density of elastane material increases more from 78 dtex to 117 dtex, a slight increase in compression pressure at the calf is observed.

Increase in compression pressure from 13 mm Hg to 17 mm Hg is due to increase in fabric contraction. The fabric density at calf increases as the linear density of the elastane material increases which gradually reduces loop length while increasing the stiffness and compactness of the fabric. As the linear density of the main yarn elastane material increases, there occurs a slight decrease in compression pressure. The reason of increase in compression pressure at thr calf is an increase in contraction that occurs in transverse and longitudinal directions.

In this study, we have changed the degree of needles which decreases from the calf portion (600) of the socks to ankle portion (300). The higher degree of needle causes the loose construction of the knitted fabric. This loose construction of the fabric allows it to stretch more as compared to the width of the calf. The socks prepared have the width ranged at calf from 24.13 mm to 26.67 mm (circumference 76.2 mm ~ 83.82 mm while the wooden dummy used in this study has a circumference of 37 cm (93.98 mm). This gradual increase in wooden dummy calf circumference shows less compatibility of the socks with the wooden leg. Consequently, due to the higher circumference of the wooden leg, extensibility of the socks and compression pressure at calf increases while increasing the size of pores.

Inlaid yarn has also a significant impact on the compression pressure at the calf. It is depicted from the figures 9, 10 and 11 that as the linear density of the inlaid yarn increases from 133 dtex to 155 dtex as a significant increase in compression pressure from 13 mm Hg to 14 mm Hg take place. It drastically continues to increase when the linear density of the inlaid elastane yarn increases from 155 dtex to 330 dtex. Hence, the intensity of the pressure can be increased or decreased by increasing or decreasing the degree of needles and speed of the elastic motor according to requisite graduation level and to achieve the desired class of compression level.

$$\text{Pressure at Calf, mm Hg} = -4.77 + 0.2734\ \text{MYELD} + 0.03171\ \text{IYELD} + 0.930\ \text{PYED} - 0.001336\ \text{MYELD} * \text{MYELD} \quad (8)$$

R-Sq. for the regression equation (2) is 92% which indicates that 92 % change in compression pressure at calf can be explained by the terms included in the equation.

CONCLUSIONS

In this study it was concluded that,

- Main yarn elastane linear density (MYELD) has significant impact on the compression pressure at the ankle. As the linear density of the main yarn elastane material increases from 44 dtex to 78 dtex an incredible increase in compression pressure from 16 mm Hg to 19 mm Hg takes place at ankle. The same effect of compression pressure at calf was observed which was increased from 13 mm Hg to 17 mm Hg and then to 18 mm Hg with consecutively increase of linear density of the main yarn 44 dtex to 78 dtex and then to 117 detx.
- Inlaid yarn elastane linear density (IYELD) has significant impact on the compression pressure at the ankle. As the linear density of inlaid yarn elastane material linear density increases from 133 dtex to 155 dtex and then to 330 dtex, a significant increase in compression pressure from 15 mm Hg to 16 mm Hg and incredible increase to 23 mmHg at the ankle was observed. The same significant influence of increase of linear densities of the inlaid elastane linear density from 133 dtex to 155 dtex and then to 330 dtex on compression pressure value at calf portion was observed ranging from 15 mm Hg to 16 mm Hg and then to 21 mm Hg.

- Plated yarn elastane draft (PYED) has non-significant influence on the compression pressure at the ankle and calf as well. As the draft value of plating yarn elastane draft increases from 2 to 3.2, a non-significant change in compression pressure at ankle from 18 mm Hg to 18.5 mm Hg and at calf from 16 mm Hg to 17 mm Hg was observed.
- Out of all newly developed V-Shape compression socks, we segregate them on the basis of graduation% values which must lies between 60% and 80%. So, on the basis of this abnormality, we rejected all the socks samples that possess graduation percentage above 80% i.e. 85% to 105% which cannot be recommended for compression therapy. For this, we found only the two samples socks, M1I3P1 and M1I3P2 acquiring excellent graduation percentages i.e. 76.19 % and 73.91%.
- Finally, we concludedthat only two socks samples (M1I3P1 and M1I3P2) that acquire maximum compression pressure at the ankle of about 21 mm Hg and 23 mm Hg along with excellent graduation percentages i.e. 76.19% and 73.91%.These socks samples (M1I3P1 and M1I3P2) can fulfill the compression pressure of class II as per UK, USA, and EU standards and of compression class III as per French standards.

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BIBLIOGRAPHY

[1] Patrice, F., Sophie, B., Jean-Louis, C. *Comparative in vitro study of three interface pressure sensors used to evaluate medical compression hosiery*. In: Dermatologic Surgery, 2010, vol. 36, issue 12, pp. 1930–40.

[2] Rodica, H., Cristina, P., Cezar Doru, R. *A new approach for testing medical stockings.* In: Textile Research Journal, 2009, vol. 80, issue 8, pp. 683–695.

[3] Hugo, P. *The use of pressure change on standing as a surrogate measure of the stiffness of a compression bandage*. In: European Journal of Vascular and Endovascular Surgery, 2005, vol. pp. 415–421.

[4] Rong, L., Yi Lin, K., Yi. L., Terence T H L., Xin, Z., Xiao Qun, D. *Objective evaluation of skin pressure distribution of graduated elastic compression stockings*. In: Dermatologic Surgery, 2005, vol. 31, pp. 615–624.

[5] Hugo, P., Bernhard, P., Walter, B. *Interface pressure and stiffness of readymade compression stockings: Comparison of in vivo and in vitro measurements*. In: Journal of Vascular Surgery, 2006, vol. 44, pp. 809–814.

[6] Bera M., Chattopadhay R., and Gupta D. *The effect of fibre blends on comfort characteristics of elastic knitted fabrics used for pressure garments*. In: Journal of the Institution of Engineers, 2014, vol. 95, pp. 41–47.

[7] Hugo, P. *Do we still need compression bandages haemo-dynamic effects of compression stockings and bandages?* Sage, 2006, pp. 21:132–138.

[8] Hui, C.L., Ng, S.F. *Model to predict interfacial pressures in multilayer elastic fabric tubes.* In: Textile Research Journal, 2001, vol. 71, issue 8, pp. 683–687.

[9] Hui, C.L., Ng S.F. *Pressure model of elastic fabric for producing pressure garments.* In: Textile Research Journal, 2001, vol. 71 issue 3, pp. 275–279.

[10] Rong, L., Yi-Lin, K., Terence-T, L., Xin, Z. *Effects of material properties and fabric structure characteristics of graduated compression stockings (GCS) on the skin pressure distributions*. In: Fibers and Polymers, 2005, vol. 6, issue 4, pp. 322–331.

[11] Gaied, I., Drapier, S., Lun, B. *Experimental assessment and analytical 2D predictions of the stocking pressures induced on a model leg by Medical Compressive Stockings,* In: Journal of Biomechanics, 2006, vol. 39, issue 16, pp. 3017–25.

[12] Homa, M., Marzie, A., A.H. S., Ali Asghar Asgharian, J. *On the pressure behavior of tubular weft knitted fabrics constructed from textured polyester yarns*. In: Journal of Engineered Fibers and Fabrics, 2011, vol. 6, issue 2.

[13] Smith, M.W.L., Dalbey, J.C. *Gradient compression hosiery knitted using core spun yarns*. In: USA, 7895863 B2, 2011.

[14] Olga, T., Wiah, W., Andrey, K., Chris W., Luca, O. *Influence of material properties and garment composition on pressure generated by sport compression garments*, In: Procedia Engineering, 2013, vol. 60, pp. 157–162.

[15] Bera, M., Chattopadhay, R., Gupta, D. *The effect of fibre blend on comfort characteristics of elastic knitted fabrics used for pressure garments*, In: Journal of The Institution of Engineers, 2014, vol. 95, pp: 41–47.

[16] Oğlakcioğlu, N., Sari, B., Bedez, T., Marmarali, A. *A novel medical bandage with enhanced clothing comfort*, In: Materials Science and Engineering, 2016, vol. 141, pp. 120–21.

[17] Rong, L., Yi-Lin, K., Yi, L., Terence, T.L. *Fabric mechanical-surface properties of compression hosiery and their effects on skin pressure magnitudes when worn*, In: Fibres and Textiles in Eastern Europe, 2010, vol: 18, issue. 2, pp: 91–97.

[18] Yongrong, W., Peihua, Z., Yiping, Z. *Experimental investigation the dynamic pressure attenuation of elastic fabric for compression garment*, In: Textile Research Journal, 2014, vol. 84, issue 6, pp. 572–582.

[19] Capurro, S. *Sheathed elastic surgical thread*, USA,*10/543333,2004.*

[20] Chimeh, M.Y., Latifi, M. Mojtahedi, M.R.M. Characterizing bulkiness and hairiness of air-jet textured yarn using imaging techniques. In: Journal of Textile Institute, 2005, vol. 96, pp. 251–255.

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Suppression mechanism study of attached apex drogue on undesirable inflation phenomena

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JUN LI
HAN CHENG
JING YANG

REZUMAT – ABSTRACT

Studiu asupra mecanismului de suprimare a ancorei apex ataşate asupra fenomenului de umflare nedorită

În prezent, studiile privind efectul de suprimare a ancorei apex ataşate asupra umflării nedorite au fost în mare măsură dependente de experimente. Experimentele au descoperit cu dificultate mecanismul de suprimare din cauza dificultății de colectare a datelor. În această lucrare, a fost propus un model FSI (Fluid Structure Interaction) bazat pe o metodă explicită a elementelor finite pentru a studia mecanismul de suprimare. Metoda grafică de deformare a fost utilizată pentru a realiza mişcarea domeniului computational. În acelaşi timp, condițiile de viteză au fost aplicate la limitele domeniului computațional, care a fost utilizat pentru a simula câmpul eolian extern. Cuplajul dintre fluid şi structura descrisă de polinomul de interpolare Lagrange a fost realizat prin algoritmul de contact. În cele din urmă, a fost dezvoltată o paraşută extra mare ca obiect de studiu, iar mecanismul de suprimare a ancorei apex ataşate a fost analizat în funcție de rezultatele numerice. Efectul diferitelor ancore apex ataşate cu diferite caracteristici de rezistenta, a fost, de asemenea, analizat de modelul FSI. Modelul şi metoda de analiză propuse în această lucrare ar putea oferi baza de proiectare a paraşutelor extra mari.

Cuvinte-cheie: țesături fabricate, paraşută extra mare, element finit explicit, metodă numerică, aplicații ale textilelor

Suppression mechanism study of attached apex drogue on undesirable inflation phenomena

At present, the studies of suppression effect of attached apex drogue on undesirable inflation were seriously dependent on experiments. The experiments were difficult to reveal the suppression mechanism due to the difficulty of data collection. In this paper, a FSI (Fluid Structure Interaction) model based on explicit finite element method was proposed to study the suppression mechanism. The graphical deformation method was used to realize the movement of computational domain. At the same time, the velocity conditions were applied on the boundaries of computational domain, which was used to simulate the external wind field. The coupling between the fluid and structure described by Lagrangian meshes was realized by contact algorithm. Finally, an extra-large parachute was taken as the research object, and the suppression mechanism of attached apex drogue was analyzed according to the numerical results. The effect of different attached apex drogues with different resistance characteristics also was analyzed by the above FSI model. The analysis model and method proposed in this paper could provide the design basis of extra-large parachute.

Keywords: engineered fabrics; extra-large parachute; explicit finite element; numerical method; textiles application

INTRODUCTION

With the growing of outer space exploration activities of human, more and more countries have developed the extra-large parachutes with nominal area of more than 1000 square meters. However, the extra-large parachutes have larger sizes and longer inflation time than ordinary life-saving parachutes. The undesirable inflation phenomena such as canopy twisting and whipping are more vulnerable to appear before removing the reefing line, and these phenomena may cause failure of recovery. The most typical example is the fourth airdropping experiments of Mars probe's parachute system in the United States in 2004, and there were two failed recovery because of the canopy whipping.

However, a large number of engineering experiments have proved that the attached apex drogue can effective suppress the undesirable inflation phenomena [1]. In fact, the attached apex drogues were generally used in American Appollo spacecraft, the Russian Soyuz spacecraft and the Chinese Shenzhou spacecraft. But the studies about suppression effect of attached apex drogue were mostly based on experiments and the related theoretical and numerical studies were less. Wang applied a multistage, multi element and multi freedom dynamic model to study the suppression effect of attached apex drogue, but the suppression mechanism based on FSI was not proposed [1]. Zhang used CFD/MSD (Computational Fluid Dynamics/Mass Spring Damper) coupling model to study the effect of attached apex drogue on inflation process, but this model was only suitable for two-dimensional calculation and couldn't simulate canopy twisting and whipping. In addition to the CFD/MSD model, there have other FSI models such as DSD/SST (Deforming Spatial Domain/Stabilized Space Time) model, IB (Immersed Boundary) model and ALE (Arbitrary Eulerian Lagrangian) model can be used to study parachute's opening process [2–5]. But most of the above models and methods used the fixed computational domain. If those models were used to calculate the parachute's airdropping process, the calculation amount would be larger and the calculation time would be longer. In addition, those models and methods ignored the effect of external wind field.

In order to explain the suppression mechanism from FSI mechanics perspective, the finite element meshes were used to describe the parachute-load system and flow field and the coupling calculation was realized by contact algorithm. Meanwhile, the graphical deformation method was applied to realize the movement of computational domain and reduce the calculation amount. The external wind field was also taken as velocity conditions and applied on the boundaries of computational domain. Based on the above model, the suppression mechanism of attached apex drogue was studied and the effect of different attached apex drogues with different resistance characteristics was also analyzed in this paper.

MATERIALS AND METHODS

In this paper, the finite element method was used to simulate the pre-inflation process of an extra-large parachute before removing the reefing line. The finite elements could track the material boundary well, therefore the mass conservation was satisfied naturally and only the momentum conservation equation was needed to solve:

$$\int_\Omega B_{Ij}\sigma_{ji}\,d\Omega - \left(\int_\Omega N_I \rho b_i\,d\Omega + \int_{\Gamma_{t_i}} N_I \bar{t}_i\,d\Gamma\right) + \\ + \delta_{ij}\int_\Omega N_I N_J\,\rho\,d\Omega\,\dot{v}_{Ji} = \boldsymbol{f}^{\text{int}} - \boldsymbol{f}^{\text{ext}} + \boldsymbol{Ma} = 0 \qquad (1)$$

where, $B_{Ij} = \frac{N_I}{x_j}$, N_I – shape function, σ – stress, ρ – density of materials, $\boldsymbol{f}^{\text{int}}$ – internal force matrix, $\boldsymbol{f}^{\text{ext}}$ – external force matrix, $\boldsymbol{M}$ – mass matrix and $\boldsymbol{a}$ – acceleration matrix.

The central difference scheme was applied in time marching:

$$\boldsymbol{v}^{n+\frac{1}{2}} = \boldsymbol{v}^{n-\frac{1}{2}} + \Delta t^n \boldsymbol{M}^{-1}\left(\boldsymbol{f}^{\text{ext}}(\boldsymbol{d}^n, t^n) - \boldsymbol{f}^{\text{ext}}(\boldsymbol{d}^n, t^n)\right) = \\ = \boldsymbol{v}^{n-\frac{1}{2}} + \Delta t^n \boldsymbol{M}^{-1}\boldsymbol{f}^n \qquad (2)$$

Both the flow field and parachute-load system were based on Lagrangian description, therefore the coupling calculation between the two could be transformed into contact calculation based on penalty function algorithm. Meanwhile, in order to simulate the permeability of fabrics, the Ergun equation was applied to calculate the coupling force f_{couple} which was taken as a part of external force $\boldsymbol{f}^{\text{ext}}$ in eqn. 1 [6].

In figure 1, the external wind field was taken as velocity conditions applied on the flow field boundaries. Meanwhile, the graphical deformation method was used to realize fluid meshes' moving to reduce the calculation amount. Three noncollinear nodes were selected randomly on load elements shown in figure 1. The coordinates of these nodes are x_A, x_B and x_C. Then a local coordinate could be defined and was given as:

$$x' = (x_B - x_A) / |x_B - x_A| \\ z' = x' \ (x_C - x_A) / |x' \ (x_C - x_A)| \\ y' = z' \times x' \qquad (3)$$

In each time step, the local coordinate would move followed the load. The transformation matrix $\boldsymbol{T}$ can be obtained by before and after the displacement of load meshes [7]. Therefore, the new homogeneous coordinate of each node can be obtained and was given as:

$$[x_1^* \quad x_2^* \quad x_3^* \quad 1] = [x_1 \quad x_2 \quad x_3 \quad 1] \cdot \boldsymbol{T} \qquad (4)$$

Here, $[x_1^* \quad x_2^* \quad x_3^* \quad 1]$ is the homogeneous coordinate after moving and $[x_1 \quad x_2 \quad x_3 \quad 1]$ is that before moving. Then the convection velocity $\boldsymbol{c}(\hat{\boldsymbol{v}} = \Delta\boldsymbol{x}/\Delta t,\ \boldsymbol{c} = \boldsymbol{v} - \hat{\boldsymbol{v}})$ which took the flow field meshes as reference can be calculated. Then, the fluid velocity was replaced by convection velocity $\boldsymbol{c}$.

After the fluid meshes distorted on each time step, the reconstructed fluid meshes was obtained by solving the Laplace differential equation and updated the flow field information by MUSCL (monotone upwind schemes for conservation laws) scheme [8].

Here, an extra-large parachute [2, 9] with nominal area of 1200 square meters was taken as the research object and the structure parameters were shown as follow in table 1. The structure parameters of attached apex drogue were shown in table 2.

It could be found in airdropping experiment that the attached apex drogue has completely inflated before the main parachute's inflation, and this paper only studied the pre-inflation process [9]. Therefore, the effect of attached apex drogue could be replaced by mechanical boundary applied on 96 nodes (figure 2) and the force of each node F_{node} was given as:

$$F_{\text{node}} = \frac{1}{2} \cdot \rho_{\text{air}} \cdot v^2 \cdot CA / n_{\text{belt}} \qquad (5)$$

Here, v is the velocity of parachute-load system, CA – the resistance characteristic of attached apex drogue, and n_{belt} – the number of reinforced belts.

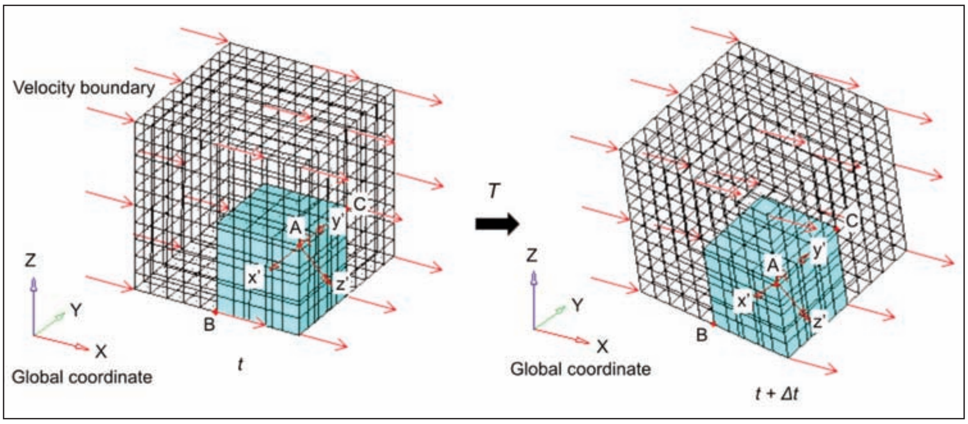


Fig. 1. Fluid meshes' motion (the cyan meshes represent load elements, the wireframe meshes represent fluid elements, and red arrows are velocity boundary)

Table 1

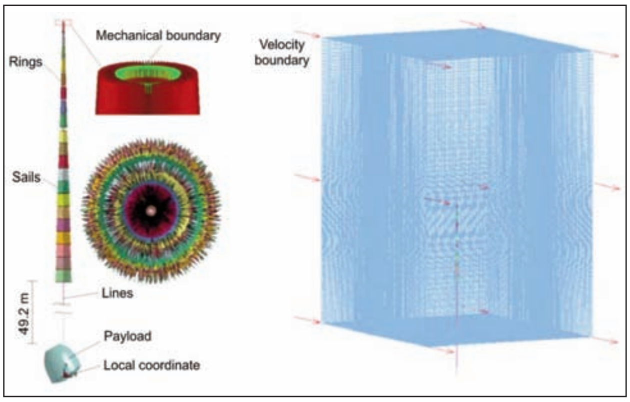
STRUCTURE PARAMETERS OF MAIN PARACHUTE	
Type of parachute	**Ringsail parachute**
Number of canopy gores	96
Number of rings	8
Number of sails	12
Nominal area (m^2)	1.2E+3
Nominal diameter (m)	39.09
Length of line (m)	49.2
Mass of payload (kg)	3.4E+3

Table 2

STRUCTURE PARAMETERS OF ATTACHED APEX DROGUE	
Type of parachute	**Rib-less guide surface parachute**
Number of canopy gores	12
Resistance characteristics (m^2)	0.8
Length of connecting belt (m)	5
Length of line (m)	1.58

Then according to the structure parameters of main parachute, the meshes model was established on real scale (figure 2). The lines and canopy were completely straightened, and the connection point of lines was fixed with load. The first four rings on the canopy top were meshed by quadrilateral shell elements (6,528), the rest of the canopy were meshed by triangle elements (85,440), and the reinforce belts and lines were by bar elements (31,400). The fluid field was described by a cube (50 m × 50 m × 74 m), and was meshed by hexahedral meshes (2,052,000). In this paper, the coupling between parachute-load system and fluid was realized by contact algorithm, therefore it didn't need to establish the complicated body fitted meshes. Both the structure and fluid meshes interpenetrated with each other.

The rings and sails of canopy were made in polyamide grid silk, the lines and reinforced belts were made in flame-retardant polyamide rope. And the material properties and initial working conditions were according to practical engineering (table 3).



a *b*

Fig. 2. Finite element model (*a* – canopy, lines and payload; *b* – parachute and fluid field)

Table 3

MATERIAL PROPERTIES AND INITIAL WORKING CONDITIONS		
Material properties of rings	Density (kg/m^3)	479
	Young's modulus (Pa)	7.3E+8
	Thickness (m)	1E-4
	Linear resistance coefficient (kg/m^3·s)	1.03E+6
	Quadratic resistance coefficient (kg/m^4)	4.5E+5
Material properties of sails	Density (kg/m^3)	512
	Young's modulus (Pa)	4.3E+8
	Thickness (m)	1E-4
	Linear resistance coefficient (kg/m^3·s)	1.1E+6
	Quadratic resistance coefficient (kg/m^4)	1E+6
Material properties of lines	Density (kg/m^3)	462
	Young's modulus (Pa)	9.7E+10
	Diameter of line (m)	3E-3
Material properties of reinforced belts	Density (kg/m^3)	462
	Young's modulus (Pa)	9.7E+10
	Breadth (m)	1E-2
Properties of air	Density (kg/m^3)	0.57
	Ambient Pressure (Pa)	4.2E+4
Initial working conditions	Velocity of parachute-load system (m/s)	100
	Contrail declining angle (°)	90
	Velocity of horizontal lateral wind field (m/s)	5

RESULTS AND DISCUSSION

Figure 3 shows the pre-inflation processes of Model A (without attached apex drogue) and Model B (with attached apex drogue).

It could be found in figure 3, *a* that both Model A and Model B were inflated from canopy bottom firstly. The air mass couldn't reach the canopy top instantly and formed the 'bottleneck' phenomenon, due to the larger nominal area. With the air entering the canopy, a symmetric vortex began to form in the external flow field and move from canopy bottom to top. At the same time, it could be found that the vortex structure in windward area was weaker than that in leeside.

With the continuous decelerating of parachute-load system, the canopy of Model A would no longer keep straight state due to the inertia force and the lack of effective constraints (figure 3, *b*). The canopy top of Model A began to appear relaxed state. And the top part began to twist and whip under the external air flow, which and gradually separated from the canopy in an asymmetric way.

From figure 3, *c*, it could be found that Model B inflated faster than Model A by the effect of attached apex drogue. The ‘bottleneck’ phenomenon of Model A and B disappeared after the ‘bottleneck’ moved to the canopy top and the vent was completely opened. The vents completely opened could signal the start of fully inflation stage. With more and more air into the canopy, both Model A and Model B began to expand from the top part the bottom. Finally, the canopies would remain as shown in figure 3, *d* because of the constraint of the reefing lines. After the formation the effective aerodynamic deceleration area, the vortexes shedding phenomenon was further aggravated.

In this paper, the pre-inflation processes of different models with different resistance characteristics (the resistance characteristic of Model C and D were 1.0 m^2 and 1.15 m^2 respectively) also were calculated by the above method and the ‘bottleneck’ phenomena also were found in these results. The ‘bottleneck’ caused the deceleration effect even weakened in pre-inflation processes, which was different from the ordinary life-saving parachutes (figure 4). But the attached apex drogues avoided the appearance of undesirable inflation phenomena (Model B/C/D), which made the time of vents’ opening earlier than Model A. It also could be found in figure 4 that the bigger the resistance characteristic, the earlier the fully inflation beginning. In addition, the attached apex drogues were helpful to reduce the overload, and had a good protective effect on the parachute-payload system.

It was worth noting that the canopy body of Model B would be more slender after the vent was completely opened because of the top constraints (figure 3, *c* and *d*). And the aerodynamic deceleration area of Model B was smaller than Model A before removing the reefing line. Therefore the deceleration effect of Model A was more obvious than others after the vent was completely opened. While the other three models had little difference in velocity changes shown in figure 5.

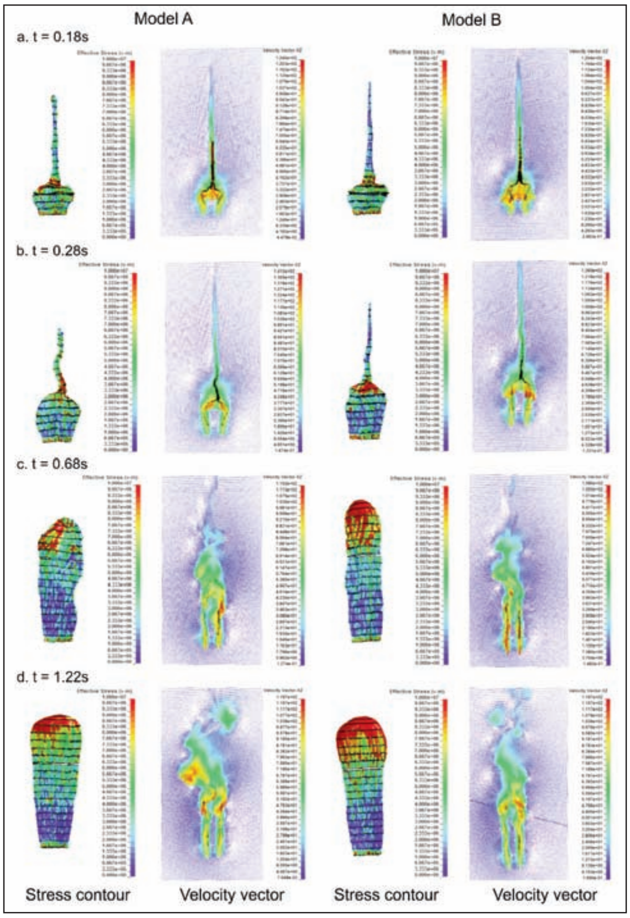


Fig. 3. Numerical results of pre-inflation processes

caused asymmetric inflating. The stress of ‘bottleneck’ part of Model A presented an asymmetric distribution. The above undesirable inflation phenomena caused the inflation process of Model A was slower than Model B. In contrast, the Model B remained a straight state by the effects of constraining force from the attached apex drogue. It could be found that there were no undesirable inflation phenomena during inflating, but the ‘bottleneck’ phenomenon still existed on Model B. The vortexes of Model A and B began to develop into more complicated and smaller

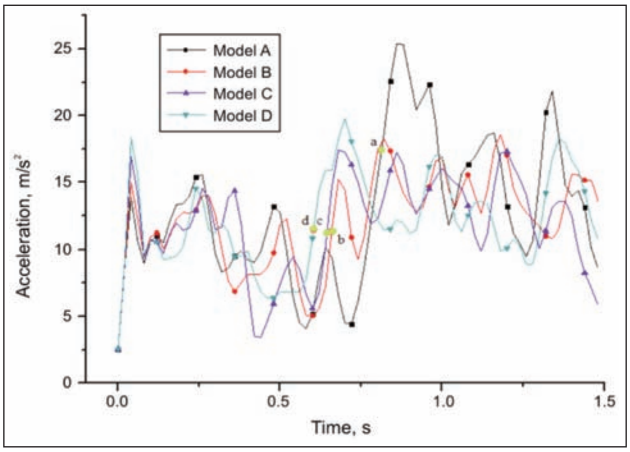


Fig. 4. Acceleration of payload (the green points labeled lowercase letter denote the beginning of fully inflation stage of four models)

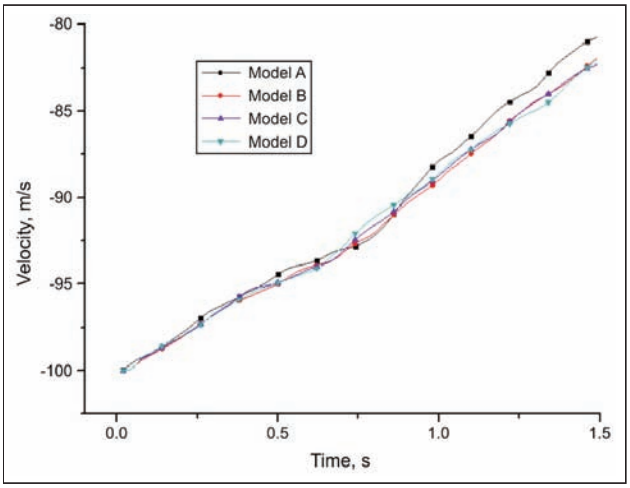


Fig. 5. Velocity of payloads

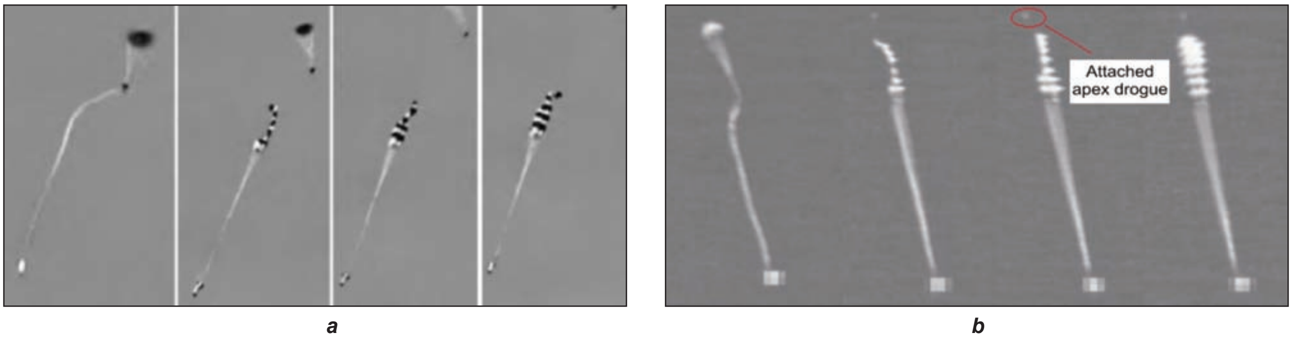


Fig. 6. Airdrop experiment: *a* – without attached apex drogue; *b* – with attached apex drogue [9]

The corresponding airdrop experiments also proved the suppression effect of attached apex drogue [9]. The serious whipping was found in the pre-inflation process of the parachute without the attached apex drogue (figure 6, *a*), while there were no undesirable inflation phenomena in figure 6, *b*. The 'bottleneck' phenomenon also was found in the actual airdropping experiment, which was the same as the numerical results in this paper.

CONCLUSIONS

In this paper, the fluid structure interaction method based on explicit finite element model was used to calculate the inflation process before removing the reefing line, and the abundant information of flow field and structure were obtained. By analyzing these numerical results, it was found that the effective top constraints were the key to prevent the appearance of undesirable inflation phenomena. In addition, the suppression effect of different attached apex drogues with different resistance characteristics was analyzed by the same numerical method. The method in this paper could provide a basis for the design and optimization of extra-large parachute system.

ACKNOWLEDGMENTS

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BIBLIOGRAPHY

[1] Wang, H.T., Qin, Z.Z., Song, X.M., Guo, P. *Effects of the attached apex drogue on phenomenon of bull whipping in the deployment process of large parachute*, In: Journal of National University of Defense Technology, 2010, vol. 21, no. 4, pp, 49–54.

[2] Zhang, H.Y., Qin, F.D., Liu, W.H., Tong, M.B. *Effects of attached apex drogue in main parachute inflation process*, In: Journal of Nanjing University of Aeronautics and Astronautics, 2010, vol. 42, no. 1, pp. 47–51.

[3] Tezduyar, T.E., Behr, M., Liu, J. *A new strategy for finite element computations involving moving boundaries and interfaces: the deforming-spatial-domain/ space-time Procedure: I. The concept and the preliminary numerical tests*. In: Computer Methods in Applied Mechanics and Engineering, 1992, vol. 94, no. 3, pp. 339–351.

[4] Kim, Y.S., Peskin, C.S. *3-D Parachute simulation by the immersed boundary method*, In: Computers and Fluids, 2009, vol. 38, pp. 1080–1090.

[5] Tutt, B.A., Taylor, A.P. *The use of LS-DYNA to simulate the inflation of a parachute canopy*, In: AIAA Report, 2005-1608, 2005.

[6] Cheng, H., Zhan, Y.N., Yang, X., Yu, L., Chen, X. *Numerical study of the permeability effect on parachute working process*, In: Industria Textila, 2014, vol. 65, no. 6, pp. 329–334.

[7] Bao, H.J., Jin, X.G., Peng, Q.S. *Basic algorithms of computer animation,* Zhejiang University publishing house, 2000.

[8] Souli, M., Ouahsine, A., Lewin, L., *ALE formulation for fluid-structure interaction problems*. In: Computer methods in applied mechanics and engineering, 2000, vol. 190, pp. 659–675.

[9] Rong, W., Gao, S.Y., Li, J. *The deceleration strategy and reliability validation of the parachute system on the Shenzhou spacecraft*. In: Science China Technological Sciences, 2014, vol. 33, no. 3, pp. 251–260.

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Alloplastic parieto-synthesis complications in abdominal wall reconstructive surgery – our clinical experience

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REZUMAT – ABSTRACT

Complicații ale chirurgiei parietale aloplastice în reconstrucția peretelui abdominal – experiență clinică

În prezent, se consideră că tratamentul eventrațiilor nu este posibil fără utilizarea biomaterialelor. Deși sunt utilizate de mai multe decenii, fiind studiate și îmbunătățite continuu, în prezent trecem printr-o perioadă de stagnare. Din punct de vedere chimic, unele materiale sunt perfect biocompatibile, dar caracteristicile fizice și structurale ale diferitelor tipuri de proteze sunt asociate cu diverse complicații, inclusiv riscul de reacții ale corpului străin, infecție, formarea seromului, obstrucția intestinală, extrudarea implanturilor, malpoziție, malrotație, eroziunea viscerelor cavitare, apariția fistulelor digestive, eșecul reconstrucției.
În încercarea de a minimiza aceste riscuri cât mai mult posibil, este necesar să se cunoască mecanismele de apariție a unor eventuale complicații.

Cuvinte-cheie: eventratie, biomateriale, biocompatibilitate, proteze

Alloplastic parieto-synthesis complications in abdominal wall reconstructive surgery – our clinical experience

Currently, it is believed that the treatment of eventrations is not possible without the use of biomaterials. Although they are used for several decades, being continuously studied and improved, now we are in a stalemate. Chemically, some materials appear to be perfectly biocompatible but the physical and structural characteristics of different types of prostheses are associated with various complications, including the risk of foreign body reactions, infection, seroma formation, intestinal obstruction, extrusion of the implants, malposition, malrotation, erosion of cavitary viscera, appearance of digestive fistulas, failure of reconstruction.
In an attempt to minimize these risks as much as possible, it is necessary to know the mechanisms of occurrence of potential complications.

Key-words: eventrations, biomaterials, biocompatibility, prostheses

MATERIALS AND METHODS

In order to objectify the complications of cure intervention of abdominal wall defects with alloplastic materials, we studied a total of 461 patients admitted and treated in Emergency Clinic Hospital, General Surgery Clinic II and Clinic of Plastic Surgery – Reconstructive Microsurgery, between January 2005 and January 2010.

DISCUSSION

It is noted that an important etiopatogenic factor in the development of eventration was represented by obesity, which was present in 27% of cases.
The chronic respiratory diseases were often a reason for wound dehiscence, due to the effort of coughing.
The impaired wound healing has been often caused by diabetes and hepatic cirrhosis.
In most cases (85%) the eventrations were symptomatic and manifested by persistent abdominal pain, abnormal bowel movements, lingering parietal suppurations, digestive fistula after alloplasty. 228 patients (49,45%) came with primary eventrations and 233 (50,54%) with recurrent eventrations (figure 1).

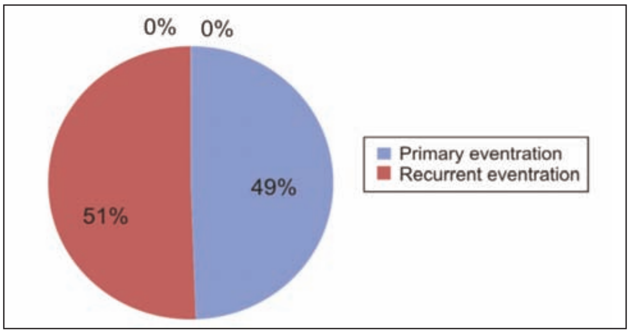


Fig. 1. Evantration cases

It should be noted that the patients with recurrent eventrations – 62% were in their first relapse, the rest having two or more relapses, with a maximum of 6 relapses.
As well, from the total recurrent cases, 58% had in their history a tissue parietal reconstruction and 42% an alloplastic reconstruction with polyesther prosthesis of autochthonous fabrication (PLASTEX).
Sixty-five patients with alloplastic parieto-synthesis in their history were admitted with a relapse of the parietal defect. Of these, 24 patients had also other late

postoperative complications associated to the relapse: 13 patients – chronical parietal suppuration, 3 patients – digestive fistula, 6 patients – intestinal obstruction, 2 patients – parietal necrosis of the abdominoplasty flap (figure 2).

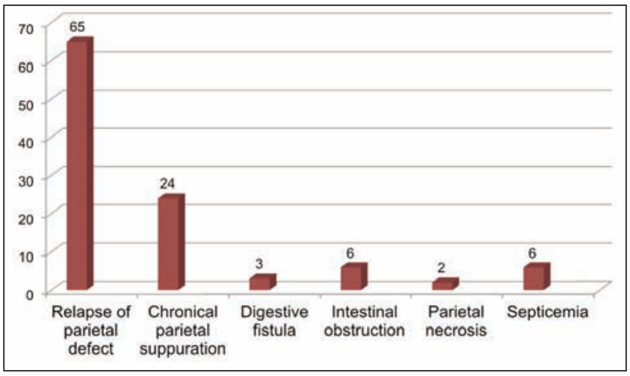


Fig. 2. Patients with recurrent eventrations

As concerns the localization of the eventration, most patients had vertical medial parietal defects and a small number of patients had other type eventrations (vertical paramedial, oblique and combined eventrations).
The vertical eventrations were of three types: medial, supra and subumbilicaleventrations in 240 patients; medial eventrations including the umbilicus – in 148 patients; paramedialventro-lateral eventrations, subcostal and iliac fossa – in 47 patients and dorso-lateral, diaphragmatic, perineal and parastomal – in 26 patients (figure 3).

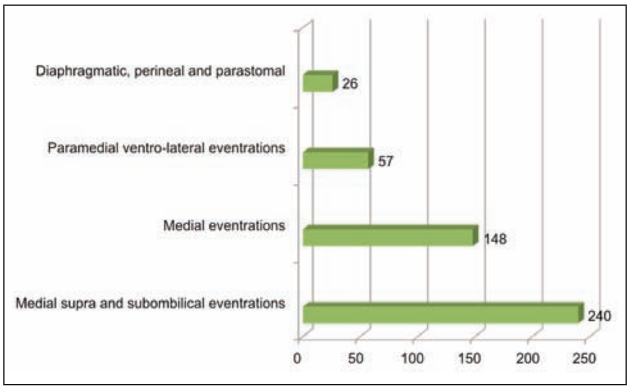


Fig. 3. Vertical eventrations

With regard to the intraoperative attitude, we found that in most cases it was possible an alloplastic parietal reconstruction in 254 patients; in the other cases – 207, the alloplasty was not possible at the first intervention because of the delayed post-operative complications, after a previous prosthetic reconstruction (chronical parietal suppuration – 13 patients, intestinal obstruction – 6 patients, digestive fistula – 3 patients), (figure 4).
The operative attitude ranged from primary prosthetic reconstruction to the draining of infections in lingering suppurations, removal of the previously implanted

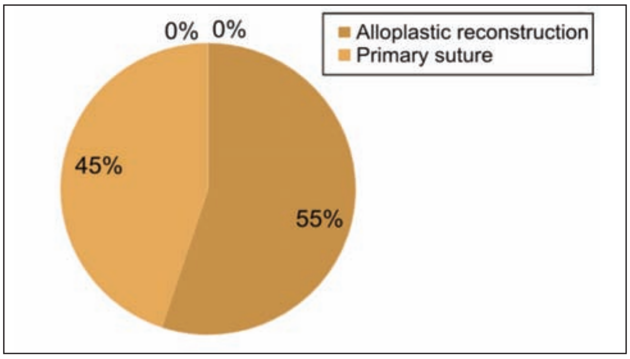


Fig. 4. Intraoperative attitude

mesh, segmented enterectomy in the digestive fistulas after alloplasty and occlusions.
Other interventions associated to alloplasty were cholecystectomy for simultaneous vesicular lithiasis in 6 cases and segmented enterectomy in 4 cases.
Implantation (positioning) of the prosthesis was performed as follows: supra-aponeurotic of consolidation – 127 cases; pro-peritoneal of substitution – 103 cases; intraperitoneal of substitution – 24 cases (figure 5).

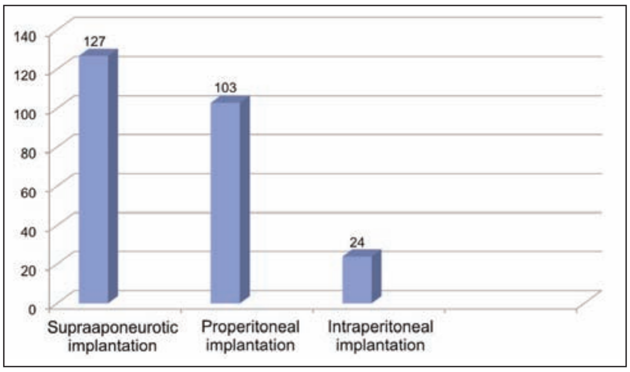


Fig. 5. Implantation pozition

With regard to the severe postoperative complications after alloplasty we found the following:
The parietal suppurations were in all cases lingering, with durations ranging from 1 month to 2 years. In all cases suppuration occurred after the use of autochthonous mesh (Plastex), generally in tarred patients with significant comorbidities.
In all cases it was required the drainage of the infectious process after the complete removal of the previously implanted prosthesis, the excision of compromised tissues.
It should be noted that in all cases the prosthesis was largely or wholly unincorporated and the pus cultures were sterile.
In most cases at the same time was performed the alloplastic parieto-synthesis under intensive antibiotic therapy and drainage.
The postoperative morbidity and mortality was 0.4%, a patient dying in the hospital through portal hypotension on decompensated cirrhosis. The postoperative complications were divided into early and late

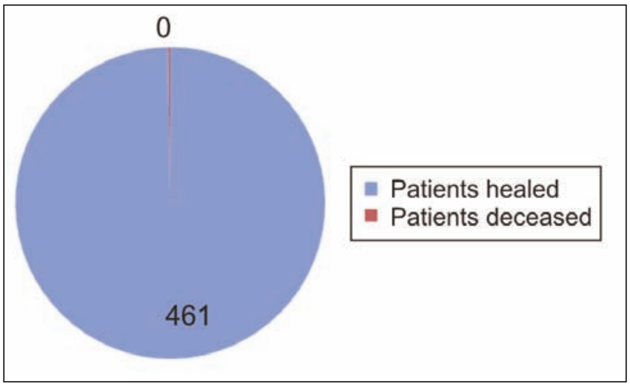


Fig. 6. The postoperative morbidity and mortality

complications, respectively in local and general complications (figure 6).
The recorded local early complications were in order of their frequency: wound infections, hematoma, seroma, dehiscence of the surgical wound.
The general early complications had an incidence of 2–4%, consisting of respiratory disorders, heart rhythm disorders particularly in obese patients with chronic respiratory disease, ischemic heart disease or hypertension.
The late complications have been linked to the presence of the prosthetic material and consisted of chronic parietal suppuration with rejection of prosthetic material, relapses of eventrations, intestinal occlusions.
The intestinal obstructions (through intestinal adhesions on the surface of the prosthesis) and the digestive fistula (through erosions induced by the prosthesis) were recorded after intraperitoneal placements of some polyester prostheses after 1–6 years interval.
It should be noted that in parietal suppurations, the removal of the old prosthesis was required only for polyester prosthesis. Polypropylene not only did not require this, but was incorporated, even in the presence of an infection.
In patients operated for giant postoperative eventrations, including also a septic time (segmental colectomies, enterotomies) to whom was used a polypropylene prosthesis, the evolution has been favorable.
Seroma recorded in this study occurred after supra-aponeurotic and pro-peritoneal alloplasty. Factors that cause them are the “dead space” which is inevitable in giant defects and the type of prosthesis. The solution is the use of macroporous mesh (polypropylene) and/or drainage suction [1–2].
The parietal infections were recorded after intraperitoneal and supra-aponeurotic alloplasty, especially after the use of “Plastex” mesh. Most often, the parietal suppuration was lingering, the patients being operated repeatedly. We have found that the excision of the fistulous tracts, of stitch granuloma and the partial removal of the polyester prosthesis were not sufficient; only the complete removal of the mesh solved the problem definitively.
The failure of reconstruction is the rule in cases where we are dealing with chronic parietal suppurations, if it was used a prosthesis made of polyester. In such cases, suppuration is a warning to the surgeon who must realize that under these conditions, the incorporation of the prosthesis is compromised.
Unlike polyester, polypropylene is inert in the presence of infection and the local toilet is sufficient. However, if the prosthesis was fixed with nylon stitches, it is necessary their removal as they maintain the parietal suppuration [4].
The risk of infection during a prosthetic implant is always possible, even if it is not completely clear in terms of incidence, severity and consequences.
In this case it is recommended the use of “clean” surgical techniques, which means the careful handling of the tissues, surgical field and prosthesis [5].
As seen, some authors recommend even the abstention from alloplasty when the surgical field is contaminated [6].
Prosthetic rejection can occur even in the absence of suppuration. Of the several types of used prostheses, we found that only for the polyester prosthesis (Plastex), which shows that this one has problems of “biocompatibility” [7].
Another cause of relapse that we have recorded in our study is the technical defect concerning the way of prosthesis fastening. In this respect, in all cases where the overlapping of prosthesis – musculo-aponeurotic edges was less than 5 cm, the patients returned for early relapse after a short period – 1–3 months.
In the prophylaxis of mesh disinsertion and relapse, the experts of parietal surgery recommend to keep a safety margin of at least 5 cm, especially at the upper and lower pole [8]. We should not forget that parietosynthesis should be performed without tension (“tension-free”) or with a lesser tension at the suture line. Neglecting of this fact is equivalent to the occurrence of relapse [9].
It should also be noted that under anesthesia the parietal tension is always lower than in the post-anesthetic period. In this regard, the consolidation alloplasty can be risky in giant eventrations, even if relaxation incisions are used [10].
In the absence of intraoperative tensiometry, the choice of the surgical technique was based on subjective criteria, in terms of personal experience. On the other hand, the prosthesis should not be set under tension because it changes its size in time, usually in the sense of contraction [11]. Of the types of used prostheses, the best results were obtained with MARLEX prosthesis. This coincides with data from international literature, where it is considered that polypropylene prosthesis is closest to the qualities of the “ideal” biomaterial.
The intestinal adhesions to the prosthesis, usually occur when the mesh is placed intraperitoneally, in contact with the viscera. Their erosion may result in the appearance of digestive fistulas, up to the migration of the prosthetic material into the lumen [12].
As we have noted in the clinical study, the prosthesis may erode both in the small bowel and colon, stomach

or duodenum. In these cases the evolution is often difficult, with the possibility of occurrence of other postoperative complications, with major vital risk.
In fact, the most difficult situation occurs when the peritoneum cannot be reconstituted and we have to position the prosthesis intraperitoneally. In this case, the best solution is the use of COMPOSIX prosthesis, considered to be best to ensure an appropriate tissue penetration and on the other side (the intestine side) a resorbable and tissue impenetrable membrane, in order to prevent the formation of adhesions and bowel fistula.
The excessive parietal tension can also cause severe respiratory and cardiovascular disorders due to the significant increase of the intra-abdominal pressure. This results in the decrease of the compliance of the chest wall with the increase of the mechanical respiratory effort [13].
Without the use of computerized systems for intraoperative measurement and correlation of the respiratory parameters, the assessment is difficult and subjective.
In addition, the deep muscle relaxation during anesthesia causes the parietal tension to be lower than in reality. We can say that giant postoperative eventration represents a true challenge both for the surgeon and the anesthesiologist.
In terms of the surgical technique, from the clinical trial results that the pro-peritoneal parieto-synthesis of substitution had the best results, provided the use of a quality prosthesis.

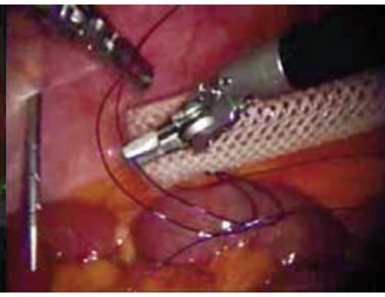
CONCLUSIONS

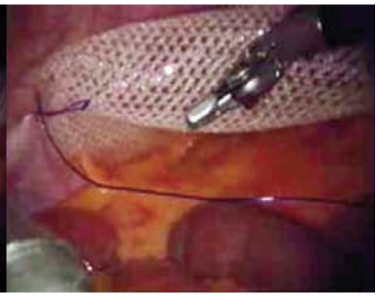
Finally, following an alloplastic parieto-synthesis all the surgeons want to preserve the physiological elasticity of the abdominal wall and the prosthesis be adjusted to the required resistance and allow an adequate tissue integration. The polypropylene prostheses show a good mechanical stability and a reasonable elasticity. The common materials with small pore size result in a foreign body reaction of relatively long duration and a strong active inflammation.
On the other hand, the conventional prostheses seem to be considerably oversized. The use of an unnecessary excess of material may lead to an excess of foreign body reaction and of an inflexible cicatricial “breastplate”, perceived by patients as a “stiff abdomen”.
It remains open the subject of foreign body reactions, which is a specific problem of alloplastic reconstructions, although sometimes underestimated.
As it was shown, the intensity of these reactions depends on the host tissue reaction, the amount of material and the structure of the prosthesis. The late parietal suppuration, the formation of adhesions or the migration/rejection of the prosthesis are the result of an inflammatory response, which is a major problem for some patients.
The long-term postoperative follow-up of the patients is essential to assess the real result of the intervention. The patient should be instructed to come regularly to control because he /she can overlook the signs of severe late complications.
The experts in parietal surgery recommend a follow-up period of 5 years.

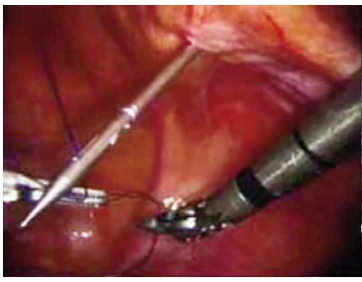
CLINICAL CASES

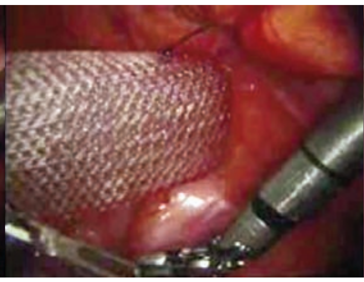
Subumbilical medial eventration repaired with da Vinci robot

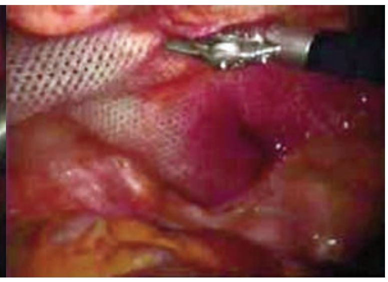

Post Burcheventration


Fastening of the first mesh stitch

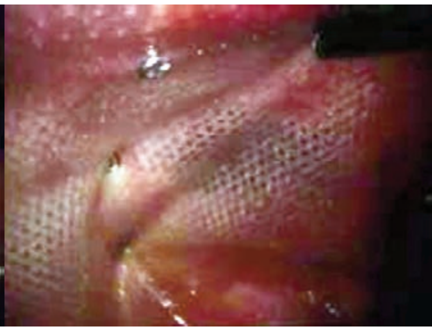

First mesh stitch knotted


Fastening of the second mesh stitch


Second mesh stitch knotted


Mesh layout

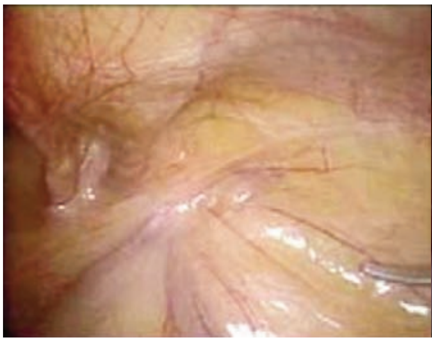
Suture of mesh margin Tackers



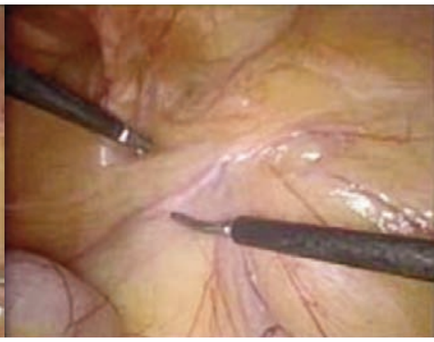
Mesh fastened with Tackers

Mesh fastened witharound the defect

Laparoscopic hernia repair



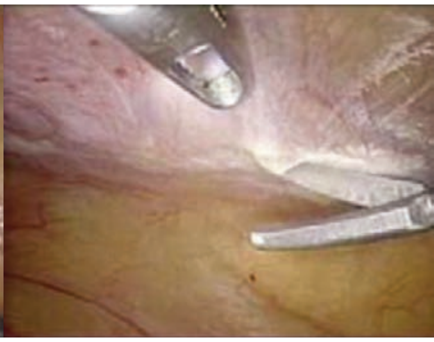
External oblique inguinal hernia (right side)



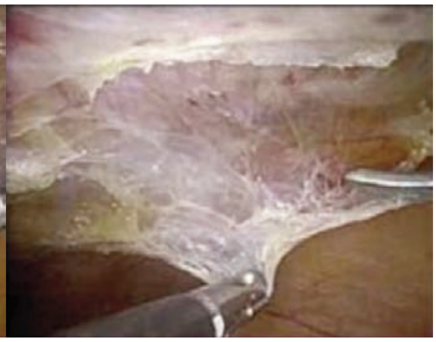
Right deferent duct

Right deferent duct-2

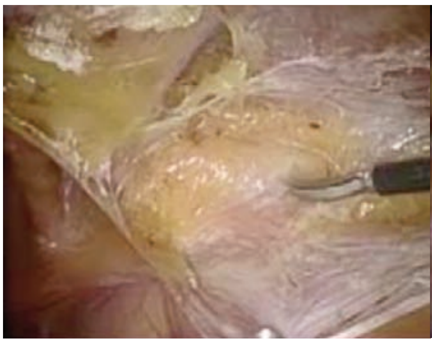
Spermatic vessels



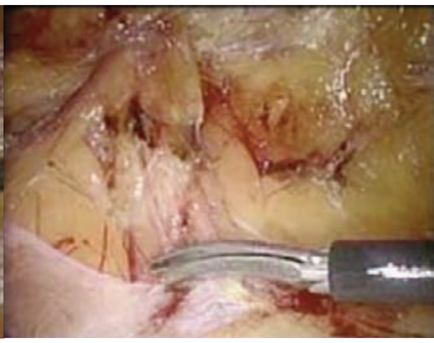
Incision of parietal peritoneum



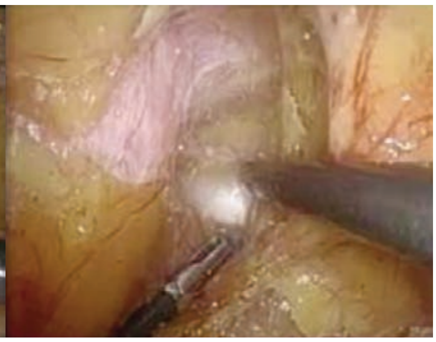
Dissection of parietal peritoneum, lower margin



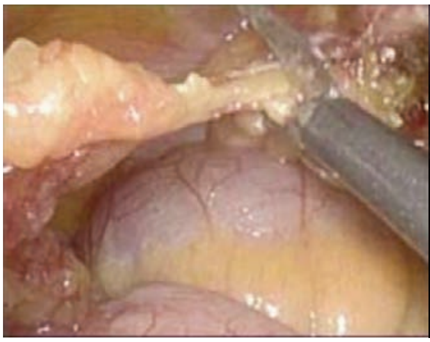
Dissection of the properitoneal space at the internal inguinal opening



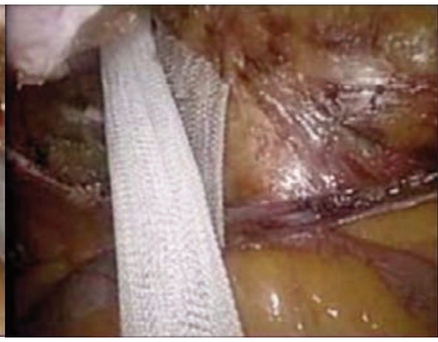
Release of spermatic funicle with fat from the marginal parietal peritoneum



Showing of Cooper ligament

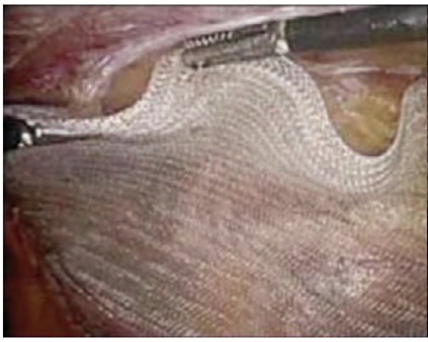


Excision of the lipomathepolypropylene mesh

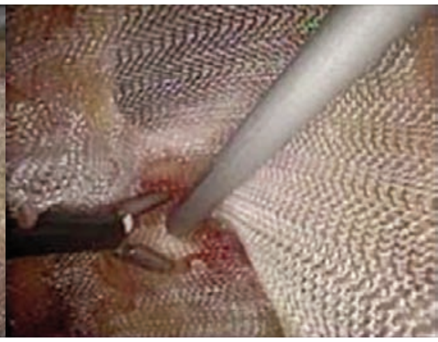


Introduction of the right inguinal region

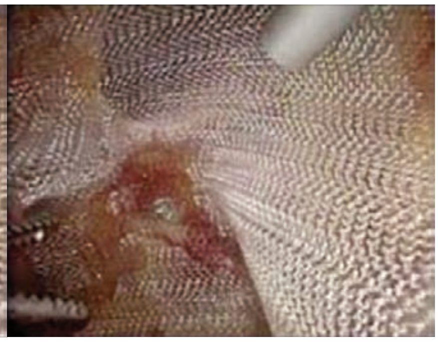
Layout of mesh ovepre-hernia



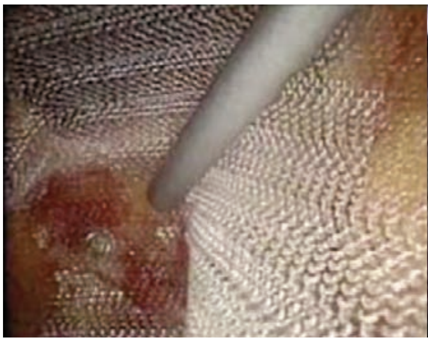
End of mesh layout



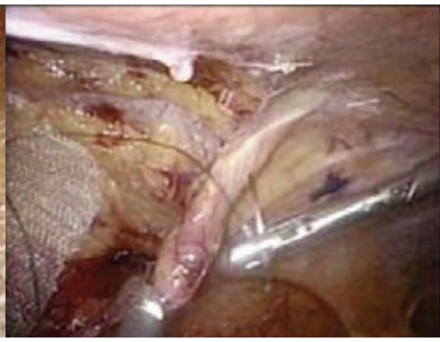
Mesh fastened with Tacker



Cooper ligament with Tacker



Mesh fastened with Tacker-2



Beginning of parietal peritoneum suture

Continuation of peritonization

End of peritonization

BIBLIOGRAPHY

[1] Feliciano, A., Bartonem G., Fei, L. *Incisional hernia*, Springer Verlag, 2008.

[2] Boissel, P., Proye, C. *Patologie chirurgicale,* Ed. Masson, 1991.

[3] Burgard, G., Marmorale, A., Cuilleret, J. *Traitement des grandes éventrations abdominales par plaque intrapéritonéale agrafée,* In: J. Chir. (Paris), 1994.

[4] Ciurea, M. *Texturi sintetice în chirurgia reparatorie a peretelui abdominal,* In: Chirurgia, 1998.

[5] Deac, D. *Utilizarea protezelor sintetice în chirurgia defectelor peretelui antero-lateral*. Ed. Clusium, 1999.

[6] Delay, E., Rivoire, M., Bobin, J.Y., Frane, C. *Réconstruction des vastes pertes de substance de la paroi abdominale inférieure,* In: Lyon Chir., 1993.

[7] Gould, B. *Collagen biosynthesis in wound healing,* USA National Research Council 1996.

[8] Slim, K., Pezet, D., Chipponi, J. *Les grandes éventrations de la paroi abdominale: un technique de plastie aponevrotique associée à une prothèse*. In: Presse Med., 1994.

[9] Soler, M., Verhaeghe, P., Essomba, A., Sevestre, N., Stoppa, R. *Treatment of postoperative incisional hernias by a composite prosthesis (polyester – polygalactin 910).* Clinical and experimental study. In: Ann. Chir., 1993.

[10] Stoppa, R., Henry, X., Abet, D., Verhaeghe, P., Largueche, S. *Que faire devant une éventration post-opératoire.* In: Cah. Med., 1979.

[11] Stoppa, R., Moungar, F., Verhaeghe, P. *Traitement chirurgical des éventrations medianes sus-ombilicales.* In: J.Chir., 1992.

[12] Schwartz, G., Brunicardi, F., Andersen, D., Billiar, T., Dunn, D., Hunter, J., Matthews, J., Pollok, R. *Principles of Surgery*, 9th Edition 2009.

[13] Voinchet, V., Aubert, J.P., Berthet, B., Mulfinger-Audiffret, C. *Apport de la plastie abdominale dans le traitement des éventrations non-compliquées de la paroi abdominale*. In: J.Chir. (Paris), 1994.

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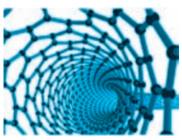

Throughput time analysis in apparel manufacturing

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GORAN DEMBOSKI MAJA JANKOSKA

REZUMAT – ABSTRACT

Analiza timpului de producție în fabricarea confecțiilor

Timpul de producție este investigat pentru linia de asamblare a cămășilor pentru bărbați în companiile producătoare de confecții. Comparația se face între timpul calculat teoretic și cel real. Timpul de producție teoretic se calculează prin timpii de întârziere la pornire, timpii de întârziere și timpii de circulație a semifabricatelor între perechile succesive de operațiuni ale traseului critic ale fluxului de productie. Se evaluează influența mărimii lotului de semifabricate asupra timpului de producție și a procesului de lucru. Comparația dintre timpul estimat și cel real, arată că timpul estimat a fost cu 10% mai mic decât cel experimental. Evaluarea efectului dimensiunii lotului de semifabricate pe parcursul întregului timp de producție și al procesului de lucru demonstrează că mărimea acestuia, poate avea o mare influență asupra flexibilității și competitivității companiei producătoare de confecții.

Cuvinte-cheie: inventar în timpul procesului, mărimea lotului, proces de lucru, linie de asamblare

Throughput time analysis in apparel manufacturing

Throughput time is investigated for men's shirt assembly line in garment manufacturing company. The comparison is made between theoretically calculated and actual throughput time. The theoretical throughput time is calculated via starting lag times, lag times and bundle times between succeeding pairs of operations of the product flow process grid critical path. The influence of bundle size on throughput time and work in process is evaluated. The comparison of predicted and actual throughput time shows that predicted time was 10% lesser than experimental one. The evaluation of bundle size effect on throughout time and work in process shows that the bundle size can have great influence on company flexibility and competiveness.

Keywords: inventory in process time, bundle size, work in process, assembly line

INTRODUCTION

Works in process and throughput time in apparel manufacturing processes are important performance indicators relating directly to plant productivity. These parameters, significant to all industrial manufacturing processes, are especially critical in apparel manufacturing, an industry marked by seasonal product lines and the necessity for rapid changes in colour, style and material. Rapid throughput time can often be the vital competitive edge in a successful manufacturing business [1]. In order to respond promptly to customer demands, it is of critical importance to shorten lead times. It was shown that application of lean manufacturing technique shortens work in process and positively affects manufacturing cost and lead times [2]. To shorten lead times, and increase flexibility, some apparel companies, besides converting to new manufacturing systems also make use of IT technology [3]. There are number of factors affecting throughput time and work in process, and companies use various manual techniques or software for their calculation. Garment industry often confronts a major issue of very high lead times despites it short life cycle and unpredictable demand [4]. Buying cycle for the garment products starts generally a year in advance and the garment companies place and process their manufacturing orders 6 months to one year ahead of the coming seasons when the product is actually required and should be available in the stores for the sales [3, 5]. Higher lead time reduces the responsiveness and increases the chances of high inventory holding and therefore, problem of overstocking. Time-based competition focuses on time reduction; it also accomplishes substantial improvements in costs, quality, and productivity. Blackburn [6] and Stalk and Hout [7], describe case studies where manufacturing firms which managed to compress lead time by redesigning their business processes, achieved higher productivity, increased market share, reduced risk level, and improved customer service. Time-based manufacturing is a weapon for time based competitors. Time-based manufacturers implement a set of work practices designed to reduce throughput time. A literature review identified seven key practices including: shop-floor employee involvement in problem solving, reengineering setups, cellular manufacturing, quality improvement efforts, preventive maintenance, dependable suppliers, and pull production approaches [8–10]. Many of these time-based practices are key elements of just-in-time (JIT) philosophy as defined by Monden [11]. In fact, Abegglen and Stalk [12] observed that some JIT innovators became the first time-based competitors as their emphasis on speed boost their skills in time reduction throughout the value-delivery system. Case studies illustrate how some manufacturing firms have applied these seven time-based practices to cut response time and enhance competitiveness [6, 13]. However, large-scale empirical studies that investigate the relationships between these manufacturing practices and throughput time are unavailable. Many firms struggle in their attempts to reduce manufacturing throughput time, while the factor changes that can reduce manufacturing throughput time are not always understood [14]. While manufacturing throughput time reduction can indeed be a overwhelming task due to the many factors that influence it and their complex interactions, there are basic principles that, when applied correctly, can be used to reduce manufacturing throughput time. To apply the principles correctly, the basic factors that determine manufacturing throughput time must be clearly understood. The existence of a certainly determined number of steps in the textile manufacturing process development makes adequate to approach the optimization of this process with stochastic procedures theory. In that case, some authors design a suitable Markov chain that shapes the production and they show how it can be applied for estimating manufacturing times. At the same time, they describe the computer software for processing practical numerical data from specific cases [15].

The paper investigates possibilities of predicting throughput time in shirt manufacturing company and compares predicted and the actual throughput time, using starting lag time formula for calculation of throughput time. Also, the influence of bundle size on throughput time and work in process is analysed.

EXPERIMENTAL WORK

The product analyzed is a men's long sleeve dress shirt. The movement of the bundle in real production is monitored through all the critical path operations of the men's shirt flow process grid. Experimental throughput time is compared to calculated throughput time. For the calculation of throughput time for complete balanced manufacturing line, the starting lag time (further in text SLT) formula is employed [16]. SLT is the time lag which is unproductive time when the operator of the succeeding operation waits to start working since the operator on preceding operation have started working on bundle. Along with numerical calculation, the graphical block method for the calculation of the starting lag time is also applied. Using starting lag time (SLT) equations, throughput time and work in process, is calculated for various bundle sizes. SLT concept assumes production line to work with minimum work in process needed to prevent creation of bottlenecks, i.e. the situations where succeeding operator must wait the preceding one, to finish the bundle before transferring job to next operation. Depending on the defining operations on time level in flow process grid, there are 4 types of job sequence relationship possible situations and respective SLT calculations:

1. Situation where smaller number of operators supply larger one:

$$SLT = LTU\ (n_1 + n_2 - 1) \qquad (1)$$

   where: n_1 and n_2 are the number of operators in first and successive job respectively, LTU – lag time unit – represents the ratio between bundle time and the number of operators.
2. Situation where larger group of operators supply smaller one: $SLT = LTU\ (n_1 + n_2 - 1)$.
3. Situation where the number of operators in two successive jobs is equal: SLT is equal to bundle time.
4. Situation where the ratio between numbers of operators in two successive jobs is whole integer which yields a fraction composed of two whole numbers where one of which is 1: SLT is equal to larger bundle time.

Before starting calculation of SLT, we must define the critical path or the longest SLT path containing sequential operations on the product flow process grid which have largest time sum when moving the job through all time levels of flow process grid. This path will determine throughput time through assembly line. Minimum throughput time is calculated by summing the SLT values of all the pairs of successive jobs of the longest SLT path in flow process grid and adding the bundle time of the critical path last operation. Work in process is calculated when inventory in process time is multiplied by line output per hour.

RESULTS AND DISCUSSION

As suggested by Solinger [16], if we want technological map in the process to be an effective tool for planning, it must be designed with the concept of mathematical graphics with the formation of networks in the Y-axis and X-axis, where Y-axis represents the timeline of the production system while the length of the spatial line the production process and layout of equipment. This timeline's measured, represents the temporal relationship that exists between the workplaces and places for temporary storage during production. Y-axis also represents the longitudinal space connection between different workplaces and places for temporary storage. X-axis also represents the lateral connection between workplaces and places for temporary storage. The work flows from the bottom of the graph, (the first level of time i.e. initial), to the upper part of the graphics till the final level of the time (last operation).

Figure 1 shows a flow network of production process of men's shirts for a bundle size of 50 pieces. The assembly of the men's shirt is done through one main and 5 subassembly lines. For this case, the longest SLT path in flow process greed is sequence of operations in front subassembly line from A1 to F10. This is so because the time for this job sequence has longest times sum of all the parallel paths.

Total production time is equal to the sum of all time at the level of the Y-axis on the critical path. Time in each level is equal to the time required to produce a certain quantity of production units. Production equipment and workers at the workplace in the graph will be equal to those which are necessary to produce the required amount per unit time at a given level.

	SLEEVES			BACK, JOKE			FRONT			COLLAR			COLLAR STAND			CUFFS		
	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators
27							F10	7.0	1									
26							F7, F8, F9	21.0	3									
25							F6	7.0	1									
24							F3, F4, F5	96.0	14									
23							F2	42.0	6									
22							F1	14.0	2									
21							E14	7.0	1									
20							E13	35.0	5									
19							E12	70.0	10									
18							E11	7.0	1									
17							E10	56.0	8									
16							E9	70.0	10							B10, B11	14.0	2
15							E8	35.0	5	C13	14.0	2				B9	7.0	1
14							E7	42.0	6	C12	7.0	1				B8	7.0	1
13							E6	42.0	6	C11	21.0	3				B7	14.0	2
12							E5	56.0	8	C10	14.0	2				B6	14.0	2
11	D9	14.0	2				E4	7.0	1	C8, C9	56.0	8				B5	21.0	3
10	D8	14.0	2				E3	21.0	3	C7	7.0	1	C1, C2	14.0	2	B4	21.0	3
9	D7	56.0	8				E2	28.0	4	C6	28.0	4				B3	14.0	2
8	D6	14.0	2	D4	28.0	4	E1	35.0	5	C4, C5	28.0	4				B2	7.0	1
7	D5	21.0	3	D3	21.0	3	A10	21.0	3	C3	21.0	3				B1	14.0	2
6				D2	7.0	1	A9	21.0	3									
5				D1	14.0	2	A8	56.0	8									
4				A7	7.0	1	A4	21.0	3									
3				A6	14.0	2	A3	7.0	1									
2				A5	7.0	1	A2	35.0	5									
1							A1	7.0	1									

Fig. 1. Men`s shirt flow process grid critical path

The starting lag time (SLT), for all successive jobs on the critical path are depicted in table 1. Starting lag time consists of bundle time and lag time. Lag time depends on a succeeding operator ratio. In our case, every operation has from 1 to 14 operators. So there are more possible ratios between numbers of succeeding operators in a production line. If the number of operators are equal, or when the succeeding operation has one operator then the starting lag time is equal to bundle time.

Figure 2 represents calculation of lag time by graphical block method for the pairs of successive operation A4 and A8. The horizontal axis represents time to complete the bundle, while vertical axis represents the number of complete bundles. The lag time by this method is obtained by overlapping blocks of two successive operations. We see that 8 operators (on operation A8) should wait 9 bundles to be produced from previous three operators (operation A4) to start working. However, after 8 operators on A8 finish the first 8 bundles and want to proceed with work, we see graphically that there are only 6 finished bundles i.e. 2 less than required. So, succeeding operators should wait additional 7 minutes to have 8 bundles prepared for 8 operators. Graphically, it is the part where two blocks overlap. Block overlapping means that the second operation A8 should start 7 minutes later after enough number of bundles have been produced (9) on operation from the previous operation

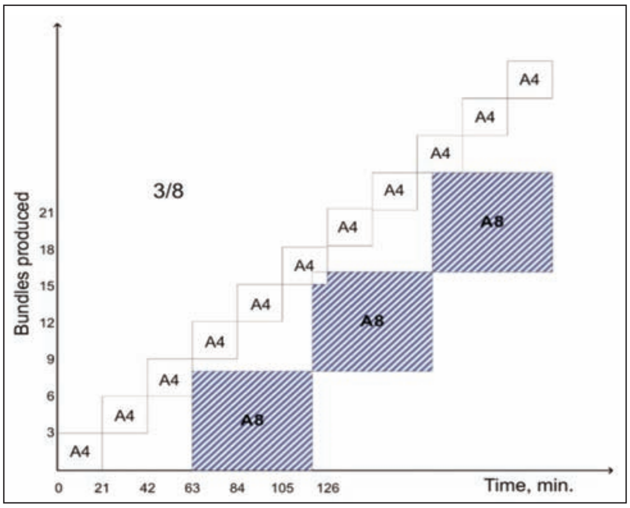

Fig. 2. Graphical calculation of lag time between operations A4 (3 operators) and A8 (8 operators)

Table 1

CALCULATION OF STARTING LAG TIME FOR CRITICAL PATH OPERATIONS FOR A BUNDLE SIZE 50							
Vertical FPG level	**Operation code**	**Operation name**	**Num. of operators**	**t_1, min**	**LT, min**	**BT, min**	**SLT, min**
1	A1	Crease left front part	1	7	0	0	0
2	A2	Topstitch left front part	5	35	0	35	35
3	A3	Crase right front part	1	7	0	35	35
4	A4	Topstitch right front part	3	21	0	21	21
5	A8	Attach pocket	8	56	7	63	70
6	A9	Sew 7 buttonholes on left front	3	21	14	56	70
7	A10	Cutt of neck opening and bottom excess	3	21	0	21	21
8	E1	Sew 8 buttons to front	7	49	0	63	63
9	E2	Close sholder seams	4	28	21	49	70
10	E3	Topstitch shoulred seams	3	21	14	28	42
11	E4	Cut off armhole excess	1	7	0	21	21
12	E5	Attach sleeves	8	56	0	56	56
13	E6	Topstitch sleeves	6	42	35	56	91
14	E7	Close side and sleeve seams	6	42	0	42	42
15	E8	Sew bottom hem	5	35	28	42	70
16	E9	Sew and topstitch collar stand	10	70	0	70	70
17	E10	Sew on cuffs	8	56	49	70	119
18	E11	Sew button to collar stand	1	7	0	56	56
19	E12	Cleaning threads	10	70	0	70	70
20	E13	Shirt inspeciton	5	35	0	70	70
21	E14	Cleaning threads by vacuum machine	1	7	0	35	35
22	F1	Put on and out shirt from vertomat doll	2	14	0	14	14
23	F2	Button up and ajdust shirt	6	42	0	42	42
24	F3, F4, F5	Fold and pack shirt	14	98	7	126	133
25	F6	Shirt control	1	7	0	98	98
26	F7, F8, F9	Pack and insert labels	3	21	0	21	21
27	F10	Put shirt in box	1	7	0	21	21
				∑	1281	175	**1456**

Codes: t_1 – time for production of 50 pieces bundle

(A4), in order to carry on operations without further waiting. These 7 minutes is actually the lag time between two operations.

Figure 3 represents graphically lag time calculation where 2 operators on operation F1 feed 6 operators on operation F2. Since the ratio of the number in preceding and succeeding operation is whole integer the lag time is zero. The starting lag time is just the bundle time. The 6 operators on F2 wait 2 operators on preceding operation to produce 6 bundles to start working and will not have to wait for the bundle till the end.

Throughput time is monitored for a bundle of size 50 in real production. The periods when operator works on bundle (bundle time) or waits for a job (waiting time) are recorded. The graphical presentation of theoretical throughput time for the bundle of 50 pieces and practical throughput time are depicted in figure 4 and figure 5 respectively. The theoretical throughput time is 1456 min while practical throughput time is 1617 min, so the real throughput time is greater that theoretical one.

This practical throughput time consists of 878 (bundle time) + 739 (waiting time) = 1617 min. The difference

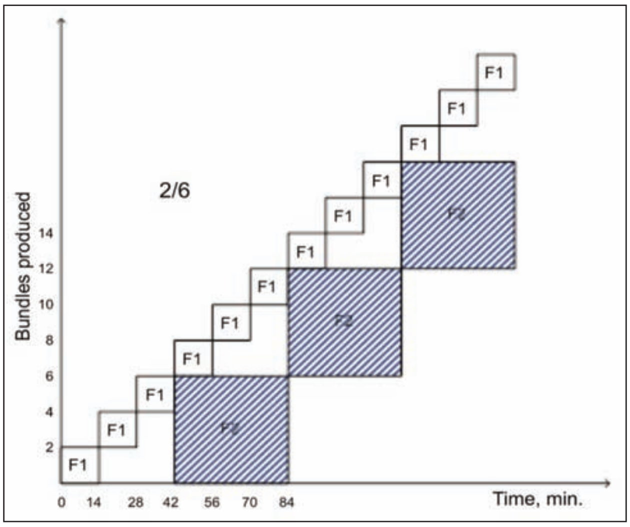

Fig. 3. Graphical calculation of lag time between operations F1 (3 operators) and F2 (6 operators)

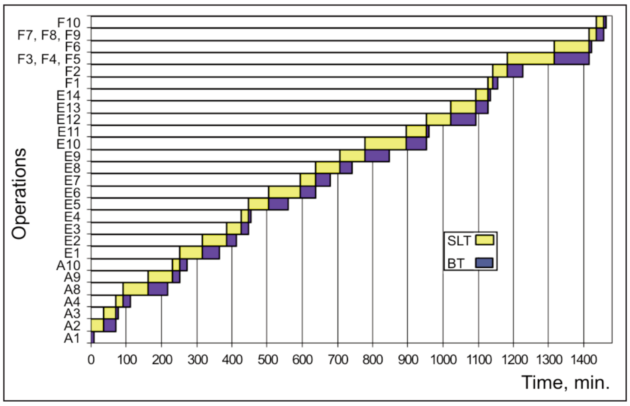

Fig. 4. Calculated throughput time in a shirt assembly line for bundle of size 50

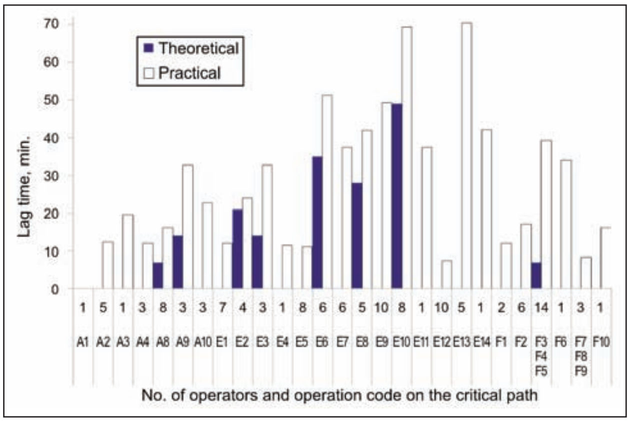

Fig. 6. Distribution of the lag time on critical path

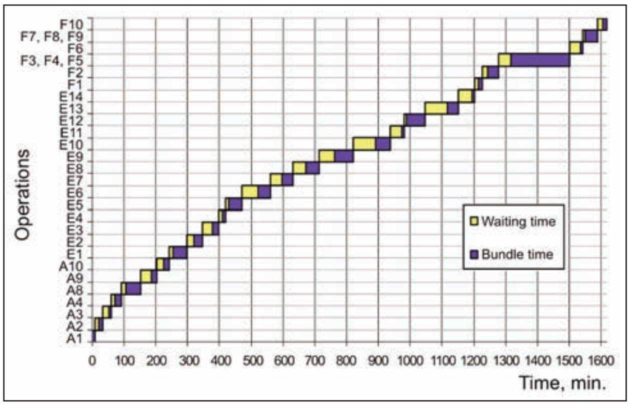

Fig. 5. Practical throughput time in a shirt manufacturing line for a bundle of size 50

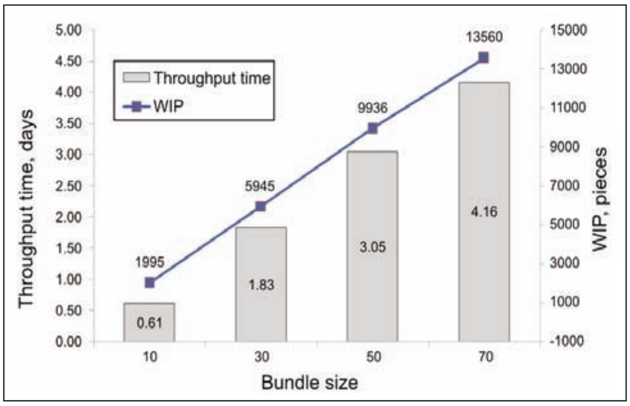

Fig. 7. Influence of bundle size on throughput time and work in process

is a result of factors influencing bundle time and waiting time in real production environment, such as: machine malfunctioning, insufficient output of preceding operation, bundle mixing, defects repairing etc. Bundle time in practical monitoring is 878 min i.e. 54% of the throughput time, while bundle time in theoretical calculation equals 1281 min which is 88% of the throughput time. Although the theoretical time is lesser than practical, it is pretty good approximation of the throughput time, since the difference between the two times is 161 min or 10%. The result confirms that this calculation can be used for predicting throughput time.

The figure 6 represents the lag time (waiting time) distribution from first to last operation in theoretical calculation and practical monitoring. Depending on the number of workers ratio between preceding and succeeding operation the theoretical lag time greatly time varies from 0 to 49 minutes. However, in practical monitoring we see even greater lag time variation and opposite to theoretical prediction, in actual production the lag time is observed at every operation of bundle progressing critical path.

Calculation of the throughput time and work in process is carried for the average size bundle of 10, 30, 50 and 70 pieces for a daily production capacity of 3054 pieces. The work in process is computed as the line output per hour multiplied by throughput time of

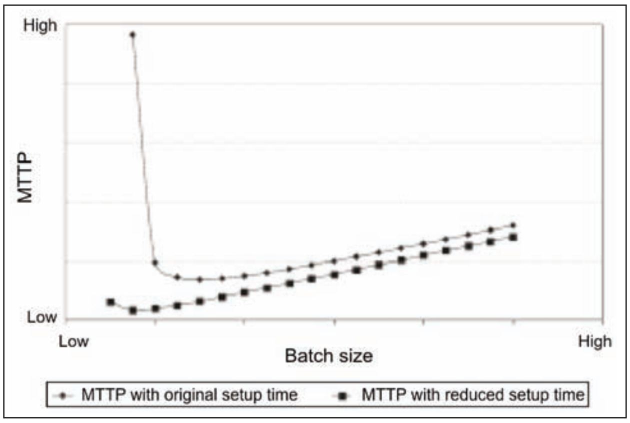

Fig. 8. Manufacturing throughput time per part (MTTP) vs. Batch Size

the bundle in production line. The results are presented in figure 7.

When bundle size increases from 10 to 70 the throughput time increases from 0.61 to 4.16 days. Consequently, the work in process increases about 7 times, from 1995 to 13560 pieces. Obviously, the smaller bundle enables faster order moving through the line and higher flexibility.

To reduce batch sizes, the plant needs to implement a policy to schedule production of smaller batches. However, if demand stays constant, smaller batch sizes increase the number of setups required. As the number of setups increases and more of the available capacity is used for setups, workstation utilization decreases, which causes queues to grow. Eventually, the increased queues negate any benefit to be obtained from batch size reduction and manufacturing throughput time per part (MTTP) increases rapidly (figure 8). Reducing setup time, as shown in the graph, would allow further batch size and MTTP reduction [1].

CONCLUSION

The throughput time in men's shirt assembly line is calculated using theoretical equations employing starting lag time formula and compared to practical throughput time obtained by monitoring bundle advancing through all the operations on assembly line critical path.

The practical throughput time for a bundle of 50 pieces was 1617 min which was longer compared to 1456 min of the theoretical one. The comparison of practical and theoretical throughput showed 10% difference suggesting that this technique can be successfully employed for predicting throughput time.

The comparison of bundle time and waiting time (lag time) percentage in throughput time showed that bundle time in real production was (54%) of throughput time, which was lesser compared to 88% of the throughput time in theoretical estimation.

The number of pieces in the bundle influences inventory in process time and work in process. For the same order quantity, the increase of the bundle size from 10 to 70 affects differences in throughput time for three and a half day and increase of the work in process from 1995 to 13560 pieces.

BIBLIOGRAPHY

[1] Johnson Danny, J. *A framework for reducing manufacturing throughput time*, In: Journal of Manufacturing Systems, 2003, vol. 22, no. 4, pp. 283–298.

[2] Senthil Kumar, B., Sapath, V.R. *Garment manufacture through lean initiative-an empirical study on wip fluctuation in t-shirt production unit*, In: International Journal of Lean Thinking, 2012, vol. 3, no. 2, pp. 1–13.

[3] Birtwistle, G., Moore, C.M., Fiorito, S.S. *Apparel quick response systems: the manufacturer perspective,* In: International Journal of Logistics Research and Applications: A Leading, Journal of Supply Chain Management, 2006, vol. 9, no. 2, pp. 157–168.

[4] Choi, T.M., Sethi, S. *Innovative quick response programs: A review*, In: International Journal of Production Economics, 2010, vol. 127, no. 1, pp. 1–12 (2010).

[5] Al-Zubaidi, H., Tyler, D. *A simulation model of quick response replenishment of seasonal clothing*, In: International Journal of Retail and Distribution Management, 2004, vol. 32, no. 6, pp. 320–327.

[6] Blackburn, J. *Time-based competition, business one Irwin*, Homewood, IL, 1991.

[7] Stalk, G., Hout, T. *Competing against time: How time-based competition is reshaping global markets*, The Free Press, New York, 1990.

[8] Davy, J., White, R., Merritt, N., Gritzmacher, K. *A derivation of the underlying constructs of just-in-time management systems*, In: Academy of Management Journal, 1992, vol. 35, pp. 653–670.

[9] Handfield, R.B., Pannesi, R.T. *Antecedents of lead-time competitiveness in make-to-order manufacturing firms*, In: International Journal of Production Research, 1995, vol. 41, no. 4, pp. 511–537.

[10] Sakakibara, S., Flynn, B., Schroeder, R. *A just-in-time management framework and measurement instrument,* In: Production and Operations Management, 1993, vol. 2, pp. 177–194.

[11] Monden, Y. *Toyota Production System: A practical approach to production management*, Industrial Engineers and Management Press, Norcross, GA, 1983.

[12] Abegglen, J.C., Stalk, G. *Kaisha: the Japanese Corporation*, Basic Books, New York, 1985.

[13] Lindsley, W., Blackburn, J., Elrod, T. *Time and product variety competition in the Book Industry*, In: Journal of Operations Management, 1991, vol. 10, no. 3, pp. 344–362.

[14] Suri, R., Wemmerlöv, U., Rath, F., Gadh, R., Veeramani, R. *Practical issues in implementing quick response manufacturing: insights from 14 projects with industry*, In: Proc. of Mfg. and Service Operations Mgmt. (MSOM) Conf., Dartmouth College, 1996.

[15] Badea, L., Constantinescu, A., Grigorescu, A., Visileanu, E. *Time optimization of the textile manufacturing process using the stochastic processes*, In: Industria Textila, 2016, vol. 67, no. 3, pp. 205–209.

[16] Solinger, J. *Apparel Manufacturing Handbook, Analysis principle and Practice*, 2nd ed., Bobin Blenheim Media Corp., 1988 Columbia, SC 29202.

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Structure with controllable permeability for vertical aerodynamic stabilizers-decelerators

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REZUMAT – ABSTRACT

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Structura cu permeabilitate controlabilă pentru stabilizatoare-deceleratoare aerodinamice verticale

Problemele științifice și tehnice legate de aplicațiile materialelor high-tech în ansamblul sistemelor de recuperare sunt deosebit de numeroase și variate. Ansamblul parașutei reprezintă cea mai importantă parte a unui sistem de recuperare, ceea ce impune o cunoaștere aprofundată a caracteristicilor de performanță în condițiile în care acestea reprezintă elemente decizionale în selectarea și proiectarea acestui sistem deosebit de complex. În acest context, lucrarea prezintă principalele realizări în domeniul proiectării și realizării structurilor destinate stabilizării-decelerării munițiilor din dotarea divizioanelor de luptă.

Cuvinte-cheie: sistem de stabilizare-decelerare, muniție, analiză structurală, calcul parametri de structură

Structure with controllable permeability for vertical aerodynamic stabilizers-decelerators

The scientific and technical issues related to the high-tech materials applications in the recovery systems ensemble are very numerous and varied. The parachute ensemble represents the most important part of a recovery system, and therefore this fact requires a thorough knowledge of the performance characteristics as they are the decision-making elements in the selection and design of this extremely complex system. In this context, the paper presents the main achievements in the field of designing and realizing the structures for the stabilization-deceleration of the combat divisions' ammunition.

Keywords: stabilization-deceleration system, ammunition, structural analysis, structure parameters calculation

ACHIEVEMENTS AND PERSPECTIVES IN THE FIELD OF DECELERATING SYSTEMS

History

Any air vehicle (considered as main system) contains the following: the propulsion system, the guidance system, the fuselage and the wings and the recovery system. The recovery system has as its components, alongside the recovery system by means of the parachute, interclassing, impact mitigation, flotation, locating, stabilizing and coupling equipment (for space vehicles) [1]. A recovery system by means of the parachute specific to supersonic aircraft and spacecraft has the following components: the airplane hold, and, apart from this compartment, the extractor parachute trigger system, the airplane link cord, the hangers, the main parachute and the case. For the ejection seat parachute ensemble, for example, the components are these: the harnesses, the binding cord, the hangers, the canopy, the main parachute case, the braking parachute, the extraction cord and the ejection seat (there may be variants of this: the main independent parachute, the altitude stabilizer braking parachute, the reactions control system RCS, the sensors for the seat stabilization) [1].

By definition, a parachute is a device designed to increase the drag of a body moving in a fluid. Since this fluid is the air, we can consider that a parachute is a particular case of "air brake" [1]. In most applications, the force that propels the body is its own weight so that the weight of the device that provides resistance has to be very low. From this viewpoint, the parachute can provide a high drag, with a very low added weight (8–12%) [1]. The military parachute is an ensemble consisting of elements which, functioning together, ensure for a given mass conditions of controlled descent, braking and stabilization as well as: the automatic opening, the parachute deployment, the loads support and the drag.

The first account of a parachute dates back to 2258–2208 BC when, a Chinese manuscript reports about the escape of Sun, the emperor of China – and the first parachutist in history – from a high tower with the help of two parachutes with which "he gets to the ground easily, without getting hurt" [2]. Leonardo da Vinci made the first sketch of a parachute during 1480–1483 (figure 1). The first successful test of a parachute was performed in 1617 in Venice by Dalmat Faust Vrančić.

The first military uses of the parachute were made by the artillery observation balloons operators during the First World War. These balloons were tied to the ground, being safe targets for the enemy airplanes, despite the strong anti-air defense [3]. The first jump with commanded opening was executed in 1919 by the Frenchman Lallemand, and the American Leslie Irving, performed the first jump with delayed opening,

Fig. 1. Model of the parachute designed by Leonardo da Vinci (1480–1483)

Fig. 2. Parachute for crew descent – rescue (Photo by courtesy of SC CONDOR SA) [1]

Fig. 3. Parachute for airborne troops deployment (Source: IRVIN AEROSPACE LTD)

after 400 meters of free fall. In the early 1920s, the plane, circular parachute, made of continuous textile material (the solid parachute), was the first parachute used to save aviators, to do sports and to parachute small loads [4]. Since 1930, the armed forces have begun to use parachutes for the deployment of airborne troops and heavy loads and for aircraft braking. Starting with 1940, the parachutes have been used to recover unpiloted planes, missiles, artillery ammunition, and later, these have also been utilized to recover piloted or unpiloted spacecraft [2–4]. The parachutes developed so far are superior to the plane – circular ones in terms of stability, opening force and drag. Some of the current parachutes can be used for supersonic applications, others for gliding descent (paragliders) [4]. However, only one type of parachute cannot provide superior performance in terms of aerodynamic characteristics.

The limits of recovery systems by means of parachutes in applications domains

Further developments have led to the conclusion that the recovery systems by means of the parachutes can be used for the following:

The airborne deployment of military personnel, equipment and technology in the final phase of transportation to the operations theater. Under these circumstances, the personnel have to be unharmed and ready for action and the equipment, intact and ready for use (figure 2). The parachutes for saving lives in air vehicles, although they are disposable (if the jump is unpremeditated) or have a limited number of uses (for premeditated jumps), must ensure extremely high functioning safety and a long-lasting technical resource (10–16 years). The parachute for *airborne troops* has to satisfy complex conditions (figure 3).

Such a parachute not only has to save life but to deploy a man who has been instructed to jump with equipment, to land in good conditions and to be ready to fight. In this situation, the descent speed must be reduced, and this can be done by using a larger diameter parachute.

The parachuting of military equipment and technology may involve deploying weights of hundreds or thousands of pounds (figure 4 and 5). Under these

Fig. 4. Parachutes system for military equipment descent [2]

Fig. 5. Low altitude parachutes extracting system (LAPES) (Source: IRVIN AEROSPACE LTD) [1]

Fig. 6. Parachute for braking at landing MiG 29 and MiG 21 LanceR supersonic aircraft (Photo by courtesy of SC CONDOR SA) [1]

conditions, the dimensions of these parachutes vary considerably, and in case the load is very high, we can use a parachute beam that opens simultaneously [5–6].

The stabilization and braking of aircraft during military operations. The first known attempt using a parachute as a landing brake was made in 1923 by means of a standard parachute for humans to reduce the landing of a Havilland biplane [7].

Currently, the stabilization of a combat aircraft is done by means of the parachute during its dangerous maneuvers: spin, stalling (at low incidence angles), wings vibration (at very high speeds). For these critical situations, the parachute is deployed and the aircraft has a normal flight attitude. Braking is used when the aircraft is in flight or is landing to reduce the braking distance, and also to protect the brakes and wheels. Worldwide, two types of braking parachutes are known, namely: – *for aircraft braking and control during flight*, known as the approach parachute; – *for aircraft braking at landing*, known as the braking parachute at landing (figure 6). This type of parachute is used, along with the aerodynamic and mechanical devices (the flaps, the aerodynamic brakes, the spoilers, the lift-dampers) to brake the aircraft during running at landing, thus producing the highest braking force at the speed with which the plane touches the ground, when the brakes are virtually ineffective [1].

Besides reducing the landing distance, the system provides increased flight safety under conditions of risk (for example during landing with non-operating brakes), during unsuccessful take-offs, during forced landings on short runways and on ice-covered or wet runways [1].

The weapons delay to enable the plane to adjust the firing, to stabilize and delay the artillery ammunition before entering the water (figures 7, 8, 9, 10) to obtain

Fig. 7. Parachute for torpedoes and mines deceleration (Source: IRVIN AEROSPACE LTD) [1]

Fig. 8. Parachute for ammunition delay - braking - stabilization [2]

Fig. 9. Parachute for weapons BSU-49/BSU-85 [2]

Fig. 10. Parachutes for lighting projectiles (Courtesy of SC CONDOR SA)

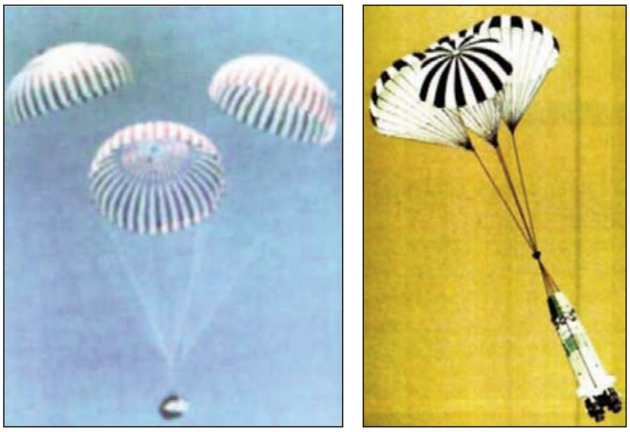


Fig. 11. Parachute for spacecraft descent, space capsules and modules planetary descent-braking [7]

the desired impact angle and an ordered distribution of the shrapnel. The parachutes used to launch fire and explosive bombs have a simpler construction than the other types and are made of easily accessible materials.

Recovery of Targets, Unpiloted Systems, Unmanned or manned boosters and Spacecraft. This operation is done by means of special MARS (Midair Retrieval System) parachutes (figure 11).

Until 1950, parachute applications were closely related to the aircraft speed and capability to fly at high altitudes [1]. Subsequent research has established that parachutes can be successfully used at speeds higher than 4 Mach at an altitude beyond the atmospheric boundaries and at a dynamic pressure of 15,000 psi (21.3 kg/m^2) [8] and can therefore be used at recovering boosters with a mass higher than 185,000 pounds (83,914 kg). The variations in these values are in close connection with the new types of raw materials and materials that appear.

Developments in this regard have led to the emergence of high performance parachutes that have been successfully used on Mars, and there are currently special preparations to recover the space capsules which will fly to Venus and Jupiter [1].

The Pioneer Venus probe was designed to study from the planet, the atmosphere composition of the telluric planet Venus (figure 12).

While entering the planet's atmosphere, the aerodynamic forces exerted on it were calculated for a level of 300 g. In addition, to be able to into account the braking of the probe, it was necessary to also consider the planet's atmosphere (sulfuric acid).

The theoretical foundation for the construction of vertical deceleration systems

The theoretical foundation for constructing the stabilization-deceleration systems was based on the theories of both Fluid Mechanics, related to: the rapid variable transient motion, the continuity hypothesis, the physical properties of the fluids, the equations of a continuous medium movement, the boundary layer, the turbulent movement, as well as Aeronautics, related to the flow of fluid around a sphere. In this regard, we considered important that the fluid is

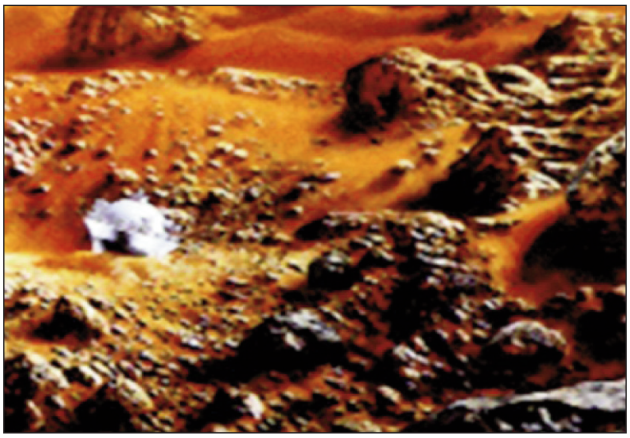
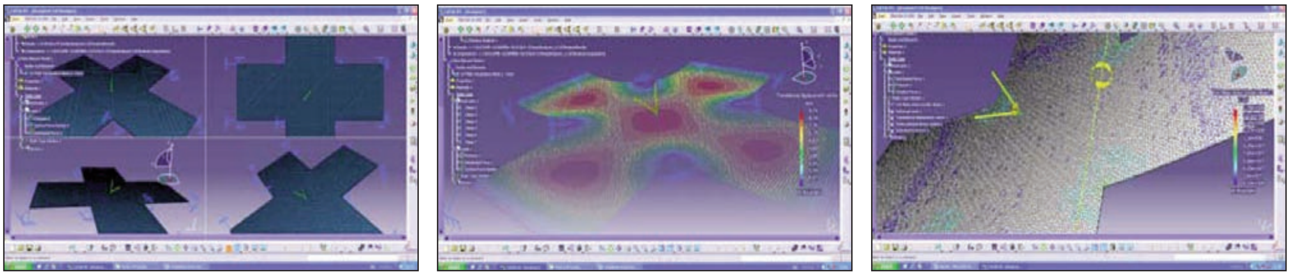


Fig. 12. Pioneer Venus Probe – NASA [1]



a *b* *c*

Fig. 13. *a* – the deformation of the canopy for ammunition with the mass of 4.32 kg; *b* – the distribution of displacement vectors for ammunition with the mass of 3–50 kg; *c* – representation of the Von Mises stress (nodal values) for ammunition with the mass of 80–500 kg

incompressible and the flow occurs in a turbulent regime. In order to design the functional model of the stabilization-deceleration system's canopy, we carried out three structural analyzes – with the assistance of specialized software – for three distinct situations, required by: the technical and tactical conditions of use (the mass, the launch height: 300–1100 m; the propulsion speed: 140–650 m/s), the effects after launch (shrapnel and shock wave), the range of the operating temperatures: (–40°C ... +70°C) the range of action (300–800 m), the propulsion type: self-destruction with 6 s delay, the illumination surface (400–800 m), the illumination intensity (200000–900000 cd), the burning-illumination time (25–45 s), the maximum force at which the canopy has to resist: 3125 N. Through the included solver, during the post-processing stage, we saw the phenomena occurring on the canopy, which allowed us to determine the variation intervals of the structural parameters. The structural analysis performed in the three situations was based on the theories of the continuous mediums mechanics. We considered that the canopy is a continuous medium that fills a certain area of space, so that at each of its geometric points, there is one material point of the medium. The geometry of the main parachute of the stabilization-deceleration system was discretized in a different series of finite elements, depending on the technical-tactical characteristics of the ammunition to be stabilized-decelerated, with the elemental mass Δm, in which the continuity property required the existence of the mass density. We took into account the actual exploitation conditions that imposed to consider the medium as being elastic, since there is no deformation after the stabilization-deceleration, the canopy returning to the initial condition. The resulting values: following the structural analysis for: the canopy deformation, Von Mises stress, the displacement vectors, the estimated error distribution (for all the three studied situations), as well as those resulting from the use of the theory without moments, allowed us to determine the main structural parameters required for the design of the structure with controlled permeability used as the canopy of the aerodynamic stabilization-deceleration system. Figure 13 shows the different stages of the structural analysis performed for the canopy as stabilization-deceleration system for ammunition with the mass of: 4.32 kg, 3–50 kg and over 80 kg, respectively.

In order to determine the main structural parameters of the fabric for the canopy, we considered the following calculation assumptions:

– the stability in operation: oscillation angle of max. ±30°; drag coefficient c_x: 0.60–0.85; low shock at opening: shock coefficient at opening c_s = 1,1–1,2; low mass and volume: 3–5% from the mass of the ammunition subjected to braking.
– the ultimate load coefficient (composed of: the safety coefficient, the dynamic load coefficient, the non-symmetric load coefficient, the coefficients due to the joints, the fatigue and the environmental factors) which affect the canopy of the deceleration parachute.

The calculations have led to the conclusion that the chosen density of both warp and weft systems is of 390 yarns/10 cm.

CONCLUSIONS

The paper presents the main achievements in the field of the structures used for the stabilization-deceleration systems of the military devices and ammunition. The theoretical foundation of the phenomena occurring on the canopy of the system was made with the assistance of specialized software that allowed us to highlight the following aspects: the canopy deformation, the displacement vectors distribution, Von Mises stress. The data obtained together with the requirements imposed on such a stabilization-deceleration system allowed us to determine the structural parameters for the fabric used for its construction.

BIBLIOGRAPHY

[1] Mihai, C. *Theoretical and practical contributions to the design and production of technical articles woven for aviation*, Doctoral Thesis – 2004.

[2] *** http://www.rumaniamilitary.ro/

[3] Brown, W.D. *Parachute*, vol. I, II, Londra, 1949.

[4] Knacke, T.W. *Parachute recovery systems, Para Publishing,* Santa Barbara, California,1992.

[5] Knake, T.W. *Techical-historical development of parachutes and their applications since World War I AIAA,* Paper No. 86 – 2423 9th Aerodynamic Decelerator and Balloon Technology Conference, Albuquerque, 1986.

[6] *** *Irvin Aerospace Ltd.* Marea Britanie, 2000.

[7] Sanger, M.B. Jr *Summary od design consideration for airplane spin-recovery parachute systems*, NASA, 1972 (Report NASA-TN-D-6866).

[8] Rodier, R.W., Moog, R.D., Kross, D.R. *136-Foot Main Parachute for recovery of Space Shuttle Solid Rocket Boosters*, American Institute of Aeronautics and Astronautics, 1984 (AIAA 84-0804).

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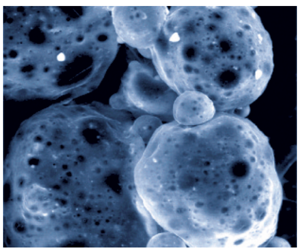

A new and sustainable service to slow fashion brands

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REZUMAT – ABSTRACT

Un nou serviciu sustenabil pentru încetinirea producției brandurilor de modă

Această lucrare explorează crearea unui serviciu inovator de închiriere a îmbrăcămintei, inspirat din "mișcarea de încetinire a articolelor de modă", care se concentrează asupra întrebării: "Sunt oamenii dispuși să poarte îmbrăcăminte second-hand și/sau închiriată atunci când călătoresc?". Acesta este un serviciu de închiriere a îmbrăcămintei de zi cu zi, dar și a îmbrăcămintei business. Crearea și dezvoltarea acestui serviciu au fost posibile prin utilizarea unei metodologii de gândire a design-ului: cadrul de 9 etape al lui Kees Dorst. În ceea ce privește validarea sa, a fost realizat un chestionar cu 430 de răspunsuri. Lucrarea prezinta răspunsul pozitiv la această problemă.

Cuvinte-cheie: sustenabilitate, gândirea design-ului, mișcarea lentă a modei, închirierea îmbrăcămintei, călătorie

A new and sustainable service to slow fashion brands

This paper explores the creation of an innovative clothing rental service, that is inspired by the 'slow fashion movement', and that focuses on the question: "are people willing to use second-hand clothing and/or leased when travelling?". This is a rental service for the day-to-day and also business clothing. The creation and development of this service was possible through the use of a design thinking methodology: the 9 steps framework by Kees Dorst. Regarding its validation, it was achieved with a questionnaire with 430 responses. The paper culminates with the positive response to the problem.

Keywords: sustainability, design thinking, slow fashion movement, clothing rental, travel

INTRODUCTION

Fashion is the way in which our clothes reflect and communicate our individual vision within society, linking us to time and space, and clothing is the material thing that gives fashion a contextual vision in society [1–2]. The fashion industry is evolving in a fast pace manner and presently witnessing situations of contradictions in consumer behavior: on one hand, consumers are becoming more conscious of the impact of their purchasing behavior, and willing to support a more sustainable fashion industry but on the other hand are complying with unsustainable business models where production is achieved to the lowest price in the shortest time possible. People say they want to become more sustainable but at the same time they cannot resist buying 'cheap' fashion. In fact, consumers' attitude and behavior are in tune with fast production [3]. Figures from the UK show that people are buying more today than twelve years ago. According to Statista (2015) in 2005 consumer spending on clothing and footwear (in million GBP) was 44.4 M, and in 2015 was 66.1 M. [4].

Experts blame fast fashion as the reason for the dramatic expansion of our wardrobes [5]. Fast production and fast consumption inevitably lead to the systematic decrease of resources and increase of waste, thus stressing the earth's capacity to regenerate at a natural pace. Guedes al (2017) state that the Portuguese clothing and textile companies have to prepare strategies to implement methods and processes capable of improving the negative image of the sector in the society [6]. This is why the 'slow fashion approach' appears as a new model that intervenes as a revolutionary process in the contemporary world. It is focused on its link with human needs, awareness and responsibility. By using the concept of slow in the fashion industry not only in Portugal, but worldwide, it is possible to re-invigorate a healthy rhythm of production, meaning that the environment and people could healthily co-exist and the earth would have time to regenerate during production cycles [1]. While fast is the opposite of slow in language; in the context of slow culture; fast and slow are not in opposition. They are different worldviews, with different economic logics and business models, values, and processes [7]. If we continue to need 'fast' or at least inexpensive fashion, we have to ask how it can be made in an entirely environmentally acceptable way, throughout the whole life cycle [8]. The slow movement questions growth fashion's emphasis on image, look, and 'the new' over making and maintaining actual material garments, re-finding earlier experiences of fashion linked to active making rather than watching [9–10]. McDonough and Braungart, in *Cradle-to-Cradle*, argue that creative sustainable design essentially means eliminating waste completely through the application of human ingenuity. Once a product has reached the end of its useful life in one form, it serves as the raw technical material, or biological nourishment, for another. That way, closed-loop industrial cycles will see recycling being replaced by downcycling [11]. Fashion and sustainability wise, there are very real practical strategies that will enable designers to specify new environmentally friendly life cycles and inspire new business opportunities that attract consumers [8].

Consumers are an important part of the fashion system because they can create a valuable influence in the pursuit of sustainability in the fashion industry. Some companies start to be aware of this new framework and are preparing new competitive strategies to give to their new consumers innovative solutions [12]. There are several aspects to consider when analyzing fashion consumers and sustainability: the consumer knowledge about sustainability, consumer behavior and consumption habits and feelings associated with sustainable consumption. In fact, the attitude and the behavior of the younger generation are in line with the rapid fashion production. Encouraged by low prices and heavily influenced by marketing campaigns and constant changes of trends, consumers tend to speed up their fashion consumption [13]. The generation Y (Millennials) are defined as a group of people born more or less between 1980 and 2000 and their core values include confidence, loyalty to civic duty, sociability, morality, intelligence and diversity [14]. Millennials maintain a positive attitude in relation to sustainability in general. Young consumers are very aware of the opportunities that companies have to help the environment and reduce the ecological footprint. Also, this is a generation that thinks that it is the companies' duty to invest in a better environment and society by producing or selling products in a sustainable way.

STATE OF THE ART

This research focuses on one main theme that is essential to the development of the service: design thinking that supports its creation and development.

Design thinking

Design thinking is described as an interesting new paradigm regarding problem-solving solutions in many different occupations, mainly in the fields of technology (IT) and also business [15]. There isn't a consensual definition of design thinking because the definitions for this concept are very confusing [17]. These authors present disparity between the concepts of 'thinking of' (design), 'thinking about' (design), and 'thinking through' (design) and suggest that the most accurate definition brings together these three different perspectives. The eagerness to adopt and apply these design practices in other fields created a sudden demand for clear and definitive knowledge about the design thinking (including a clear definition). For Cooper, Junginger and Lockwood, design thinking (think through design) involves the ability to quickly visualize problems and concepts, the development of scenarios based on people, and the construction of business strategies based on designers' research methods [17]. Lockwood defines design thinking as being essentially a process of human-centred innovation that emphasizes the note, collaboration, rapid learning, visualization ideas, a quick prototype of concepts and analysis of business competitors. Brown states that design thinking is about observing an unclear phenomenon and try to look at it away from conventional scenarios in order to preview future scenarios [16]. In this way, by using an appropriate business strategy, it is possible to turn customers' needs into value and create a market opportunity.

Kees Dorst describes a new approach, which focuses on problem-solving innovation in organizations that is called the creation of frames [18]. Dorst applies design thinking, but goes one step ahead of the tricks and techniques that regularly characterize it. Creating frames focuses on the ability to create new approaches to the analysis of the situation of the problem itself, and not only on creating solutions to problems. The strategies suggested by Kees Dorst are drawn through the consistent practices in several sophisticated and unique layers from top designers, and also through ideas that emerged from 50 years of research in Design [18]. Dorst describes nine steps in the process of creating frames and illustrates its application to real-world problems. It maps innovative solutions and provides tools and methods to implement the creation of frames, in other words, it is a way of thinking in design that helps professionals to develop their own approaches to problem solving and creating innovation along with the Design. This way it is possible to see companies as a series of frames: frames for resiliency, Kees Dorst [18]. The 9 steps are:

1 – Archaeology of the problem (why is it the problem? how did it become a problem? Why haven't been solved? who has this problem?);
2 – Paradox (what makes this problem difficult to solve?);
3 – Stakeholders (who are the stakeholders?);
4 – Problem Arena (what else is part of the problem?);
5 – Themes;
6 – Frames;
7 – Future;
8 – Transformations (what needs to change to be implemented?);
9 – Connections (how does it connect to the rest of the world?).

RESEARCH METHODS

The main research goal of this paper is to analyse the feasibility of a service of this kind and realize its acceptance, in order to respond to the problem: "Are people willing to use second-hand clothing and/or leased when traveling?". The methodology adopted in this study (table 1) is based on a quantitative approach, resorting to a questionnaire technique.

Table 1

Specific objectives	Methodology
Creation of the service	9 steps framework
Validation of the service	Questionnaire

TRAVELING NEVER FELT SO LIGHT

The proposition on this paper is an exciting new clothing service that respects slow fashion and points towards the promotion of sustainable lifestyles. The way it works is simple: different types of clothes and accessories from different brands can be rented, via online or via store, and then delivered at the desired location (e.g. hotel, resort, and company) or picked up at the store (figure 1). After they are used they return to be carefully and environmentally washed so they can be reused. Besides everyday clothes, it is a service that also provides suits and outfits for business trips, depending on the associated brands in the destination of choice. The idea behind this service is for the associated fashions brands to offer a new experience to their customers, a luggage free trip. Free of all the packing drama and everything around buying new and specific clothes for certain destinations. In sum, this is a service that gathers several brands, and works as a link between the brands and their customers. Besides offering a new fashion experience, the brands are also promoting a slow fashion approach, due to the constant circulation of clothes.

After some research on the subject, the use of second-hand or rented clothes has not yet been given much thought in the way this service intends to act, so this is a problem that ends up becoming a business opportunity. At the time being, the only type of clothing that is possible to rent are carnival costumes and garments for specific events, usually parties and galas. Also, the differentiation would be in offering all kinds of clothes, with the possibility to also rent depending on the type of country (for example: snow clothes for the Nordic countries or beach wear for the hot/exotic countries). Still, the service offers the possibility of renting clothes for business trips. Promoting a new sharing economy and respecting the slow fashion movement, clients can drop off clothes in exchange for new clothes, and this way there is good circulation fomenting the reuse of clothes and experimentation. This way, looking for a collaborative economy can enter as a solution to the crisis we face today, since this is based on economic, social, technological and environmental pillars. And that is exactly what this new service promotes: an economy in which people are the focus, and the exchange of goods and services between themselves, in this case, clothing and accessories, contributes to a healthy growth, not only mind-set wise but also of economies. It should be noted that, in accordance with the results of the questionnaire people feel awkward in acquiring second-hand products. To overcome this constraint there are various complicated stages, among which raising awareness to solutions such as the proposed service. It is also necessary to ensure total cleanliness and quality of clothes, to try to minimize the stigma about the use of clothes already used by other people. The biggest obstacle to the use of this type of service is the doubt in the consumers' minds if the clothes are clean enough and ready to use without having to question its cleanliness. These problems came up during the questionnaire, and were a very important insight for the development of the service.

Design thinking: 9 steps framework by Kees Dorst

The section below presents the application of the 9 steps framework to the new service:

1. Archaeology of the problem. The research question became a problem from the time when the economic crisis in Portugal started. From that moment, there was a decrease in purchasing power, forcing people to direct their income for other less superfluous goods. It is a problem that was never solved because there is not yet a rental service that enables the customers to rent clothes for every occasion and not only for special events and that also promotes exchanging clothes for new clothes or store credit to be later used in renting. This is a philosophy that encourages a collaborative economy, by promoting sustainability values. The main holder of this problem is anyone who travels and/or that has true sustainability concerns, and as the questionnaire will show, the Millennials are the generation with the most worries about sustainability and that show a greater acceptance for these kinds of sharing services.

2. Paradox. According to the questionnaire results, this is a problem that is difficult to solve because people don't like the idea of using second hand clothes. They have doubts concerning its quality and cleanliness. This resistance to leased and/or used clothing is what makes this a complicated problem to solve.

3. Stakeholders. The interested parties are all the associated brands willing to be a part of this new fashion experience, the community in general (partnership with travel bloggers; and business partners as advertising agencies), institutions (airports, municipalities and national tourism departments) and lastly, all customers who are able to share the same vision, and thus join the service. Essentially, it is expected that the adhesion to this service is made mainly by people that are part of generation Y (also known as Millennials), that support and share a more collaborative vision.

4. Problem arena. Not all is about clothes, but education in a way. Another concern that is inherent in the problem is the luggage. The fact that tourists have to pack causes an inconvenience to the extent that they need to select the clothes they want to take, and later, the psychological cost of a potential loss of bag is quite high. With this service, the tourist's clothes are "safe and sound" at home, and they don't need to worry at all with luggage. It is only necessary to bring their essentials (hygiene). Also, by not bringing their clothes, they are offered the experience of trying clothes that they don't own, to step outside their comfort zone if they feel like it. That said, this is an ultimate fashion service that exists not only to facilitate the travelling moment but also to make it an unforgettable fashion moment, as it promotes sustainability and all the brands associated to it.

5. Themes. In this step the themes start to emerge, and they are the bases for new frames. In this case there are four major themes for the service to exist: clothes and accessories; Physical stores, Website and mobile application (figure 2).
6. Frames. The main frame is its motto: "Traveling never felt so light". This is because tourists don't need to take anything with them. On the other side, they bring home a baggage filled with great experiences and fashion moments that are only emotional and not physical. This is how this service wants to position themselves, because looking at the problem from this perspective, shows that being a part of this fashion experience serves to enrich and not only to facilitate the traveling moment.
7. Future. Nowadays society is more susceptible to a collaborative and sharing way of living, either in the sense of physical goods, experiences or information. This service is just one of the mechanisms of this collaborative economy, where people can share tastes, styles, goods, but, above all, experiences.
8. Transformations. This is the complicated step because in order for this service to succeed, the mentality of people when it comes to renting clothes that has already been used by third parties needs to change. For this to be possible a major campaign of demystification of the service needs to be in correctly done. With good communication, people can understand the advantages clearly. As will be shown by the questionnaire results, the question of hygiene and cleaning of the clothes is in fact a barrier and a huge resistance.
9. Connections. If this reaches the needs of the population in general, it has the potential of becoming a social collaboration tool. That way this model can be quickly replicated in other cities around the world, always respecting the way of dressing and the fashions of each culture and country.

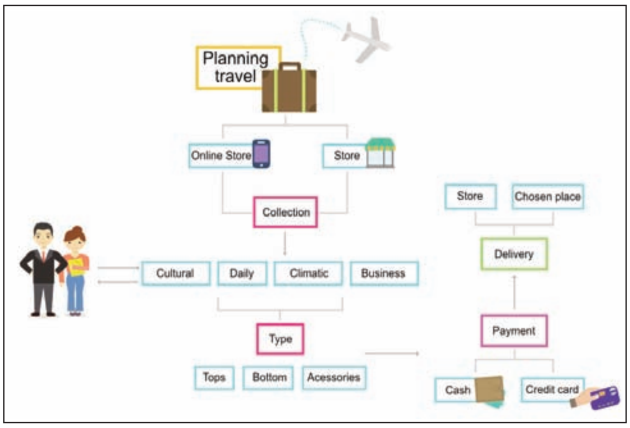

Fig. 1. How the service works

RESULTS AND DISCUSSION

To allow an analysis of the feasibility and acceptability of a service like this, a questionnaire was conducted in two parts: the basic characterization of the respondents and the analysis of the feasibility and acceptability of the service. The questionnaire was completed by 430 individuals, and was applied via online. Demographically the majority of respondents are female, with a total of 273 responses, representing

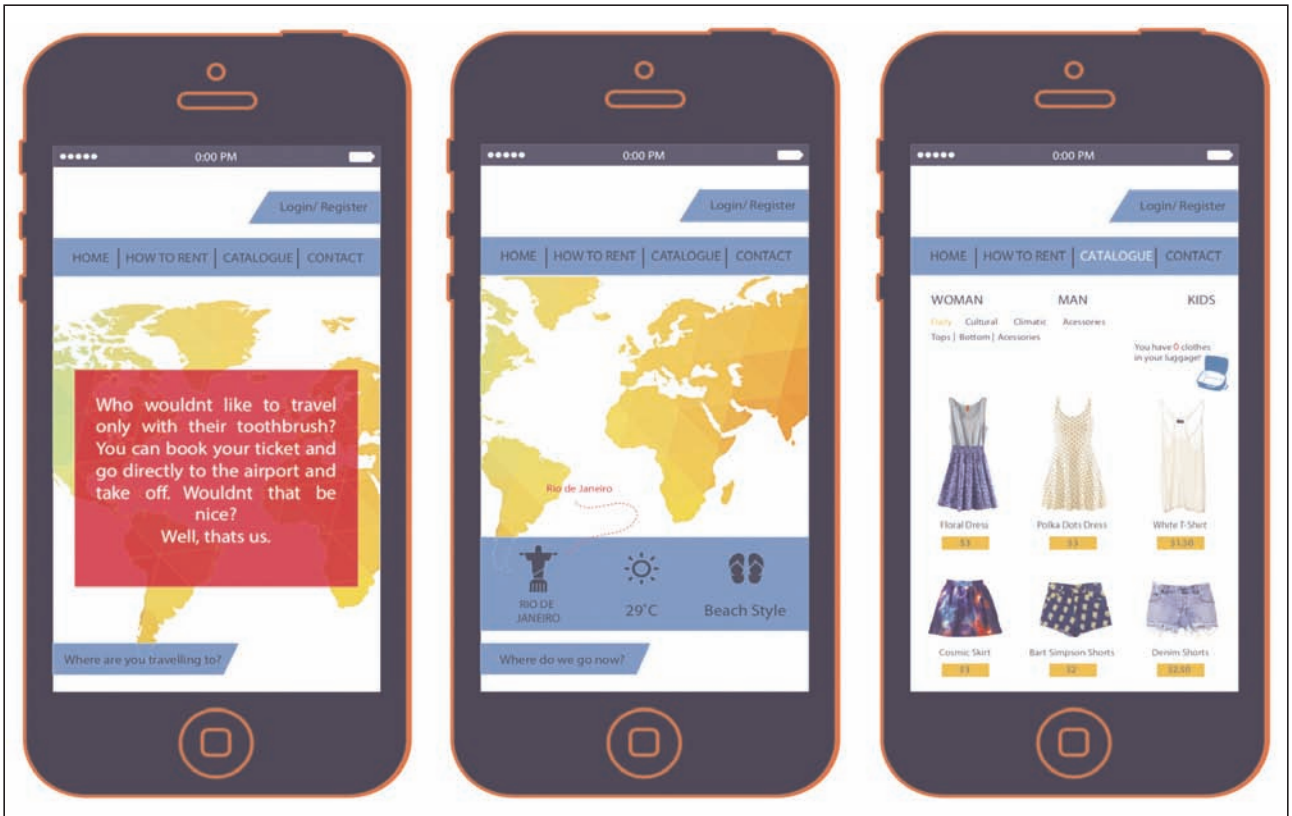

Fig. 2. App mockups

63.5%. The males represent 36.5% of the sample, making a total of 157 responses. Regarding their age, the majority focuses on the age group of 21 to 30 years, followed by the age group of 18 to 20 and 31 to 40. Therefore, the target audience, which are the respondents aged between 18 and 30 years (Millennials), represent 56% of the total responses. Regarding the district where the respondents live, the majority belongs to the District of Porto (40.5%) and Aveiro (30%). Although the questionnaire reached all districts of the country and Islands, the North of Portugal was the one that had a higher incidence of responses, making a total of 79.4% that translates in 341 individuals. The District of Lisbon also had a significant amount, resulting in a total of 48 responses (11.2%).

In terms of the analysis of the viability of the service, the respondents had to answer if they usually buy clothes to take on trips. The majority (60%) answered "Yes", and 40% who do not. This means that most people spend part of their budget on the purchase of new clothes for travelling, with the possibility of these clothes being seasonal and have little use after the trip. Respondents were also asked regarding the type of benefits they seek when purchasing clothes when they travel. Quality and price had the biggest response rate having 344 and 321, respectively. This means that there is a consistent demand for a product that has an excellent price-quality ratio.

The question "Do you consider using or have you used something borrowed or in second-hand?" was the most important for the validation and acceptability of the service. That way, 82.1% responded "Yes", i.e. 353 people responded positively. Only 77 of the respondents said they wouldn't use something used/borrowed. The respondents who answered "Yes" were then questioned regarding the type of borrowed or second-hand products they have used or would consider using. The responses "Clothing and accessories" and the "Educational materials" were the answers with higher incidence, having the first obtained 213 positive responses, and the second 221. It is possible to note that the respondents are willing to wear second-hand clothes and accessories.

The respondents were then asked if when travelling to a place whose climate is quite different than what they are used to, if they usually buy clothes suitable for that particular climate. This way, 75.3% responded "Yes", i.e. 324 people claim to have bought clothes when they go traveling to a different climate country. This translates in an investment in clothing that is used only a few times since they are to be used in a very different climate. So, by renting clothes/accessories suitable for all climates, allows travellers to save money.

The next question is also one of the most important parts of the questionnaire, because it questions the respondents "Would you use rented or in second-hand clothes or accessories?". The response was very positive because 66.5% (286) of the respondents answered "Yes" and only 33.5% (144) replied "No". To those who responded "Yes" in the previous question, a new question was applied trying to figure out for what purposes the clothes and accessories were/would be used. Clothes for "parties and events" and "Day to day clothes" achieved the highest number of responses, with 63.2% and 59.3% respectively. Therefore, and since this is a service that intends to focus on clothes for day to day, business and for special events, the answers are quite positive for the project. The number of responses is reflected in a strong acceptability in the use of this type of clothing. Those who answered "No" were able to justify their answer. Of the 144 negative answers, only 105 responded. Therefore, the majority of respondents does not use rented or in second-hand clothes because they "Don't like it" (37%), and because they believe that "It's not sanitary" (26%). Also, one of the predominant reasons that came up as an obstacle to the use of this type of clothing is the fact that travelers do "Not know the history of use of the clothes", with 21% of the responses.

Finally, and in order to figure out if the lack of hygiene and cleanliness is one of the eliminating factors to the use of second-hand and/or rented clothes and accessories, the respondents who replied "No" to the question "Would you use rented or in second-hand clothes or accessories?", were questioned if the quality and cleanliness of the clothes is guaranteed, if they would change their negative answer to a positive one. An astounding 39.5% of the 144 negative answers changed it. Therefore, only 87 of the 430 total respondents wouldn't wear second-hand clothes or accessories. That way it is possible to affirm that 343 of the total of 430 respondents would be in fact willing to wear clothes or accessories rented and/or in second-hand.

Similar conclusions were obtained in previous studies using the focus group methodologies. In this qualitative approach, all the participants of the focus group responded positively to que question "Have used or considered using something borrowed/used?", and referred as justification: the economic aspect because it allows saving by avoiding ongoing investments in new clothes and still be able to find different clothes, which encourages experimentation. Also, after the focus group it was perceived that this is an innovative service that will be very well received, as long as the partnerships are made intelligently and the quality and hygiene of the clothes is well communicated [19].

CONCLUSIONS

This is a new and exciting service that is born to be a new way of promotion of a more sustainable society, encouraging different consumption habits and approaching fashion in a way that promotes a shift from fast to slow fashion, changing the way we consume clothes. The research problem was positively answered, showing that people are willing to use second-hand clothing and/or leased when traveling but only if the cleanliness and hygiene of the clothes are guaranteed, and all participants showed a high interest in a service like this. However, the main limitation of this study is that the results from the analysed sample are 100% Portuguese, therefore it is not possible to extrapolate these results to other countries where this service would like to be present. Different market studies are needed to a better assessment of the business, and also, different contacts with clothing brands must be made in order to understand their willingness to join a sustainable and more conscious way of being in the world.

BIBLIOGRAPHY

[1] Fletcher, K. *Sustainable fashion and textiles: design journeys,* In: London: Earth Scan, 2008.

[2] Cataldi, C., Dickinson, M. and Grover, C. *Slow fashion: Tailoring a strategic approach towards sustainability,* In: Masters' thesis; Karlskrona, Sweden: School of Engineering, Blekinge Institute of Technology, 2010.

[3] Morgan, L., and Birtwistle, G. *An investigation of young fashion consumers' disposal habits*. In: International Journal of Consumer Studies*,* 2009*,* vol. 33, pp. 190–198.

[4] *Statista (2015) Expenditure on clothing and footwear in the UK.* In: Retrieved on March 2017. Website: https://www.statista.com/statistics/289996/expenditure-on-clothing-and-footwear-in-the-united-kingdom-uk/

[5] Dirksen, K., *Fashion guide I: Slow fashion,* http://faircompanies.com/news/view/fashion-guide-i-slow-fashion, 2008.

[6] Guedes, G., Ferreira, F., Urbano, L. and Marques, A. *Corporate social responsibility: competitiveness in the context of textile and fashion value chain*, In: Environmental Engineering and Management Journal, 2017, vol. 16, no. 5, pp. 1193–1202, ISSN: 1582-9596.

[7] Fletcher, K. *Slow fashions: An invitation for Systems Change*. In: Fashion Practice, 2016, vol. 2, no. 2, pp. 259–266, DOI: 10.2752/175693810X12774625387594.

[8] Blackburn, R.S. *Sustainable textiles: Life cycle and environmental impact* In: Cambridge: Woodhead Publishing Limited, ISBN 978-1-84569-453-1, 2009.

[9] Clark, H. Slow fashion – An oxymoron or a promise for the future? In: Fashion Theory, 2009, vol. 12, no. 4, pp. 427–46.

[10] Thorpe, A. *The Designer's Atlas of Sustainability*. In: Washington, DC: Island Press, 2007.

[11] McDonough, W. and Braungart, M. *Cradle to cradle: Remaking the way we make things* In: New York: North Point Press, 2002, ISBN-13: 978-0-86547-587-8.

[12] Marques, A., Guedes, D., and Ferreira, F. *Competitive strategies in fashion industries: Portuguese footwear industry,* In: IOP Conference Series: Material Science and Engineering, 2017, vol. 254, DOI: 10.1088/1757-899x/254/20/202006.

[13] Birtwistle, G. and Moore, C.M. *Fashion adoption in the UK: A replication study*. In: Paper presented at the Anzmac Conference Brisbane CA, 2006.

[14] Zemke, R. *Here come the millennials*, In: Training Magazine, 2001, vol. 38, no. 7, pp. 44–49.

[15] Brooks, F. *The design of design: essays from a computer scientist*. In: NJ: Addison-Wesley Professional, 2010.

[16] Martin, B. *Change by design: how design thinking transforms organizations and inspires innovation*. In: Harper Collins, New York, 2009.

[17] Cooper, R., Junginger, S. and Lockwood, T. *Design thinking and design management*: A research and practice perspective. In: Design Management Review, 2006, vol. 20, no. 2, pp. 46–55, DOI: 10.1111/j.1948-7169.2009.00007.x

[18] Dorst, K. *Design problems and design paradoxes*, In: Design Issues, 2006, vol. 22, no. 3, pp. 4–17.

[19] Bernardes, J.P. and Nogueira, M. OKG: *creating and developing an innovative clothing service,* In: IOP Conf. Ser.: Mater. Sci. Eng., 2017, vol. 254, 212001, DOI:10.1088/1757-899X/254/21/212001.

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The concept of fashion marketing as an instrument of reducing tensions between designers and marketing experts in fashion companies

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REZUMAT – ABSTRACT

Conceptul de marketing de modă ca instrument de reducere a tensiunilor dintre designeri şi experții în marketing din companiile de modă

Tensiunile dintre designeri și experții în marketing din companiile de modă sunt create în mare măsură deoarece valorile de design se opun valorilor marketingului. Printre altele, o mai bună înțelegere a conceptului de marketing de modă, care se bazează pe respectul egal pentru design, clienți și profiturile companiilor de modă, contribuie la limitarea neînțelegerilor. Acest fapt a fost confirmat de cercetările efectuate în țările din Balcanii de Vest.

Cuvinte-cheie: tensiuni, designeri, experți în marketing, concept de marketing de modă

The concept of fashion marketing as an instrument of reducing tensions between designers and marketing experts in fashion companies

Tensions between designers and marketing experts in fashion companies are created largely because the design values are opposing to the values of marketing. Among other things, a better understanding of the concept of fashion marketing, which is based on equal respect for design, customers and profits of fashion companies, contributes to the reduction of misunderstanding. It has been confirmed by research carried out in the countries of the Western Balkan.

Keywords: tensions, designers, marketing experts, fashion marketing concepts

INTRODUCTION

Design integrates functional, ergonomic and aesthetic qualities of products and is an effective instrument of diversity in relation to competitive products. To achieve this, designers must effectively connect these features or aspects of art to the market, in order to create the appropriate product for the previously selected market target.

Therefore, considering the business from the perspective of customers does not exclude the simultaneous interest in profit. Moreover, if there is no active search for profit, the ability of the company to meet customers' needs for a longer period will be significantly reduced.

The authors who have dealt with the study of tension between the design and marketing as key business functions in fashion companies, among others, are: M. Vasiljević [1], H. Bloch Peter [2], B.B. De Mozota [3], J. Bohdanovich, L. Clamp [4], M. Gašović [5], H. Yen [7], Ph. Kotler, L. Keller [9], K. Best [10].

The following authors have especially dealt with the relationship between designers and marketing experts: M. Easey [6], B.M. Beverland [12], D. Zhang [13].

Research results of the mentioned authors point to a pronounced complexity of the fashion market. Such a fact objectively imposes a lot of difficulties to designers and marketing experts, whose activities are very intertwined and dependent on each other.

Tensions between designers and marketing experts have been the subject of the study of the authors of this paper as well. Publications of the mentioned authors, who did research in this area, were initially considered. That activity has resulted in the synthesis of their views presented through the parts of this paper with the headlines: The views of designers; the views of marketing experts. Then, during the 10th and 11th months of 2015 it was published primary research on a sample of 50 fashion companies in the Western Balkans. It was conducted a survey of designers engaged, as well as the survey of the Heads of Design Departments in larger companies. On the other hand, depth interviews were conducted with 20 marketing experts. Due to the large scope marketing activities covered, it has been discussed with various persons who are directly addressed in cooperation with designers. Interviewed artists are the designers of fashion garments in the field of knitwear, lingerie, denim and, mass market product. They expressed their opinions by answering to ten questions related to: freedom to create, participation in decision making on assortment, perception and the role of marketing, existence of disagreements with marketing experts, causes of the disagreement, etc.

Interviewed marketing experts announced their views on: the role of design in product differentiation, misunderstandings with the designers, the causes of these misunderstandings, disagreements when designing price, making the selection of fabrics, the requirements of key customers, validation and acceptance of the results of marketing research, etc. They are engaged in their companies as: consultants of marketing issues, head of marketing departments, independent associates for marketing issues, sales managers, agents and managers of retail stores.

SUBJECT, OBJECTIVE AND RESEARCH METHODOLOGY

The subject or issue of this paper refers to the misunderstandings between the designers and marketing experts in the fashion companies that produce garments. The operational definition of the subject of research is focused on companies that produce fashion products for the mainstream market in the countries of the Western Balkan.

In this research the authors try to identify the causes of the tensions between the designers and marketing experts, and discover the common ground between their points of view.

Starting from the object and purpose of the research, two hypotheses have been imposed. The first hypothesis is that tensions between the designers and marketing experts are real. The second hypothesis is that their relation and cooperation can be improved by better understanding and implementation of the fashion marketing concept which presupposes equal respect for both designers and marketing experts' views.

Several methods of research were applied in the paper. The initial method used in this research should show the dominant point of view of renowned authors who have discussed the relations between designers and marketing experts in fashion companies. The primary research was done based on sources taken from literature mentioned in Introduction.

The research method authors used is the field research (surveys with designers and interviews with marketing experts) are made in order to collect data and information from primary sources. Other methods presented in this paper are: descriptive method, method of analysis and synthesis, method of concluding, etc.

The method of sample selection for surveys and interviews was conditioned on the size, success, product range. The way how managers and/or owners of the companies treat their designers and marketing experts of their companies has also been a criterion. The sample size of 50 fashion companies in a relatively small region as Western Balkans is truly representative. According to the method of selection, it is a deliberate sample. This sample type was selected because the researchers were familiar with the structure of the fashion market in the Western Balkans.

The respondents were the head designers, leading designers and designers-external associates who were engaged by contract for designing work in fashion companies.

Interviews were realized with 20 marketing experts who had to cooperate with designers because of their unique work position. Most often these were: heads of the marketing departments, consultants for marketing jobs, independent associates for marketing jobs, sales managers, agents and managers of larger retail stores.

THE VIEWS OF FASHION DESIGNERS

According to M. Vasiljević, author of numerous publications in field of fashion design, fashion products are considered to be a result of a fashion design process [1]. Likewise, designers require that design is seen as an additional attribute that is added to the value of products. There are four key components of products that make up the design of fashion products different from competitors'. In addition to the aesthetic component (shape, colour, style), there is a technical and functional component (functionality, reliability, performance, reversibility) and ergonomic component (comfort). The design of packaging and labels, as an integral part of the overall product design without which products cannot enter the market, is also designers' responsibility. The designers do not mention at all the role of marketing, nor the requirements and desires of customers which can be obtained during marketing activities.

P. Bloch, the author who deals with the relationship between product design and marketing, says that designers emphasise their design principles that have an impact on customers' preference and are the basis for understanding of their aesthetic reaction [2]. The principle of shape of the product is the principle of "unity" or "whole". Many different elements form the shape of the product, and they are all selected and united into a whole by the designer, with the purpose of causing a sensory effect. Designers make decisions, not only on the shape of the products, but also on their size, proportion, material, colour, ornaments, texture, etc., in order to form their optimal combination. These design statements ignore marketing research in terms of customer perception regarding the aesthetic component of design.

According to B.B. De Mozote's research, designers' attitude regarding the brand stands out [3]. They demand that the relationship between design and brand is not reduced exclusively to graphic design, logo or sign. Rather, design is present in all aspects of brand equity: mission, promise, positioning, feeling (expression) and quality. All non-verbal elements of the brand (colour, logo, appearance) can be designed. Graphic design refers to the name and symbol of the brand, while the design of a product is related to its performance. The design of packaging refers to packaging appearance, and interior design refers to the layout of retail stores.

L. Bohdanovich and M. Clamp, famous names in the fashion marketing, claim that top designers create garments of haute couture [4]. This type of products is available only to premium customers and they are offered with other fashion items such as jewellery and cosmetics. These are unique items, mainly produced by the rules determined by the world's fashion centres such as Paris, Milan, London, etc. The originality and quality of these models are guaranteed, and

control is performed by specialized institutions Chambre Syndicale da la Couture Parisienne.
M. Easey, a renowned British author in the field of fashion marketing emphasizes that some designers believe that marketing is just a promotion [6]. Practically speaking, the designers are the real strength and they just need an advertising or effective PR to keep customers or make them discover their creations. The current and potential customers are considered to be persons who should lead and inspire creative clothing that was successfully promoted. Persons who can appreciate the creative clothing are the wealthiest strata of the society. Designers believe that it is necessary to monitor the activities of persons who are presumed to be located at the forefront of creative change (film directors, musicians, artists). Many of great fashion designers represent this stand and lead a successful business.

THE VIEWS OF MARKETING EXPERTS

M. Gašović [5] warns that marketing experts occasionally experience designers as artists, undisciplined and insensitive to costs and profitability. This stems from the fact that they are first and foremost economists who are trained for the systematic and analytical approach to problems. According to them, the application of marketing involves identifying objectives and specifying the funds invested in the research, production, promotion, sale, etc. Marketing experts believe that success comes as a result of careful research and planning, rather than as a result of spontaneity or ignorance of market reality. They often fail to understand the aesthetic dimensions of design or many qualitative aspects of product development. Also, sometimes they lack awareness of the role of design in business. Marketing experts often treat designers as persons who need to respond to the kind of customer specification as defined by marketing research.
According to B.B. De Mozoti [3], marketing experts expect from the designers to have unique ideas and create products for specific market segments. After that, these products are positioned at the certain segments, but also in the minds of customers. According to this view, access to the positioning defines the creative freedom of the designer in terms of the desired level of differentiation – from completely original to the adapted product. In doing so, the designer can define alternative positioning which correspond to the benefits of certain market segments.
M. Easey [6] points out the view of so-called 'marketing fanatics' who believe that marketing concept is the solution to all business problems, i.e. that its application may pay for failures in the design of products and prevent a decline in profits. Also, they do not recognize the interdependence of operational and creative business functions within the company. Also, marketing fanatics do not understand enough business environment.

The author H. Yen [7] in his research comes to conclusion that there is a close link between Marketing Strategy and Design Strategy. He classifies marketing strategies into four groups: strategy for market leaders, strategy for market challengers, strategy focused on market and strategy focus on market niches. Each of these strategic alternatives suits an adequate strategy, which designers agreed on.

INTERPRETATION OF THE RESULTS OF RESEARCH ON THE VIEWS OF DESIGNERS AND MARKETING EXPERTS IN THE FASHION COMPANIES IN WESTERN BALKANS

The first questions in the questionnaire referred to highlight of the decision-maker about assortment (design solutions) which will be offered to the market. The largest number of respondents, 58% of them, believes that it is the owner or chief director. Designers make decisions in 22% of cases, and marketing experts in 20% of situations. Therefore, managers-entrepreneurs style (who make up the majority), problematic privatization, a painful transition, low purchasing power and a permanent economic crisis, undoubtedly reflect the weak impact of primarily designers in fashion companies in the Western Balkans (figure 1).

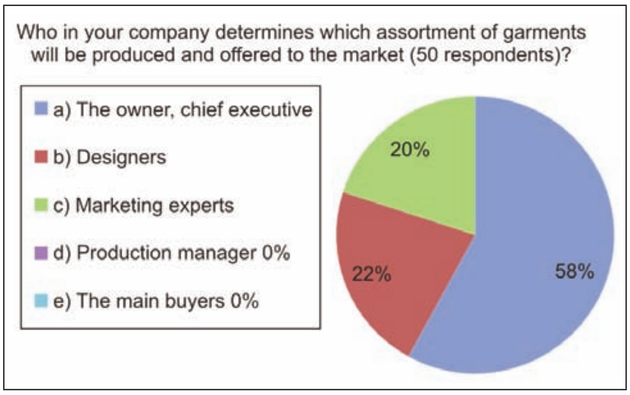

Fig. 1. Decisions-makers about assortment of garments that will be produced and offered to the market

The issue was related to the importance of some of the business functions in the companies in which designers work. The answers are really indicative. In fact, 40% of respondents believe that the design is an important element, while slightly less – 38% of them think it's a marketing function. It is encouraging that the production function is dominant in only 22% of cases. From the above it follows that the design and marketing as business functions, integrated and with reduced tension, can be the powerful force in business strategies of fashion companies (figure 2).
The third question was about the level of creative freedom of designers. Even 66% of respondents believe that they have partial freedom when designing garments. Others, 18%, says they have no freedom, while 16% claimed to have total creative freedom. If the number of designers who have partial

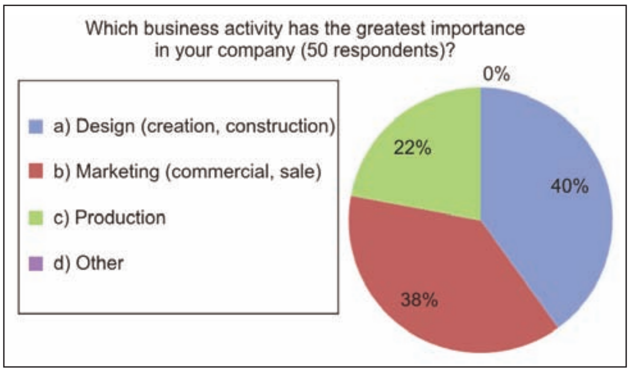

Fig. 2. The business activity that has the greatest importance in companies

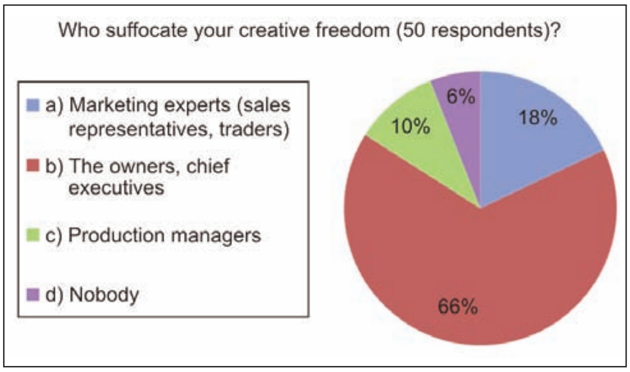

Fig. 4. Perosns that suffocate crative freedom in companies

freedom and those who have full autonomy is viewed together, it can be concluded that the creativity of designers and their freedom to create is more and more respected in the fashion companies in the Western Balkans, which is very encouraging (figure 3).

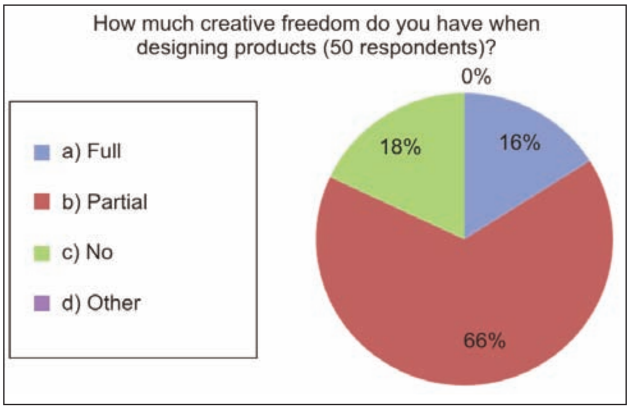

Fig. 3. The level of creative freedom in products designing

Fourth issue is aimed to get an answer of designers on the person in their companies who stifles their freedom and spontaneity in creating garments. A large percentage of respondents, or 60%, believes that those are owners or chief executives. Marketing experts are considered culprits by 18% of designers, and production managers by 10% of them. It is indicative that only 6% of respondents said that no one stifled their creativity. So, it is obvious that the owners (usually the managing directors as well), who are the vast majority of the founders of fashion companies, have not yet left the initial syndrome of entrepreneurs-managers – intended to fully control all the jobs in their own companies (figure 4).

Replies of designers to the fifth question, which referred to the understanding of marketing as a whole of activities (product development and branding, pricing, promotion, distribution, sales) were surprisingly positive and accurate. In fact, 96% of respondents believe that marketing is a whole of given activities, and only 4% of them equates it with the sale, which is only one of its functions, the final one by which the full effort of designers and marketing experts, as well

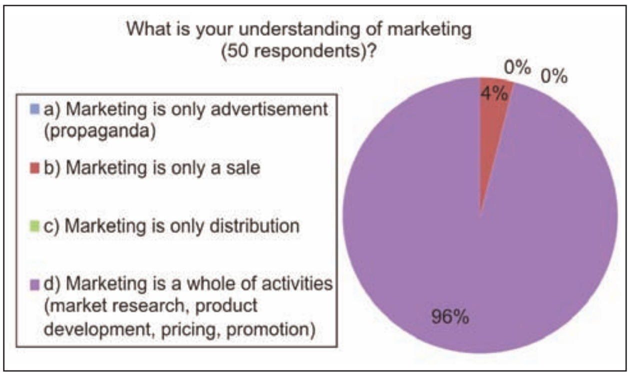

Fig. 5. Understanding of marketing

as other business functions in companies, is realized (figure 5).

The sixth question referred to the disagreement of designers and marketing experts in their companies. About two-thirds of respondents, or 68%, said that the disagreement occurs only in certain specific situations. For the reply "yes" or permanent disagreement was answered by 12%, while 6% of the respondents did not answer the question. Starting from the given answers, it can be cautiously concluded that tensions between marketing experts and designers still exist, but that disagreements are rarely manifested, which is a sign of their reduction (figure 6).

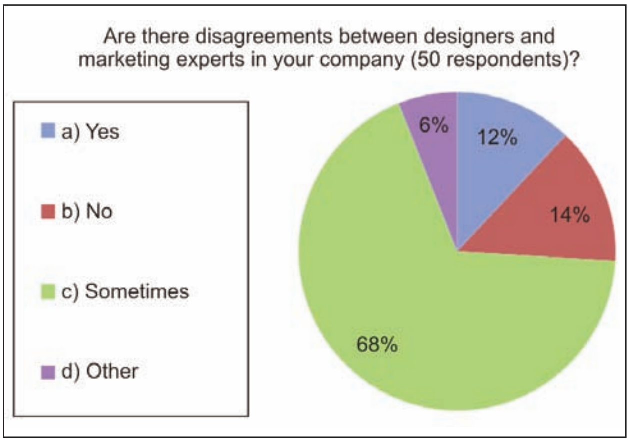

Fig. 6. Existence of disagreements between designers and marketing experts in companies

Question seven asked designers to answer on the causes of their disagreement with marketing experts. More than half of respondents, or 56%, claim that the main reason lies in the unwillingness of marketing experts for market risk when it comes to the adoption of new, original design solutions. For the offered answer that suggests the impossibility of expressing their creative potential through the acceptance of their models, 8% of respondents opted, while 10% of them consider that marketing experts underestimate their knowledge, talent and effort. However, a significant percentage of respondents, 26%, gave a self-critical response about mutual misunderstanding as the cause of disagreement between designers and marketing experts (figure 7).

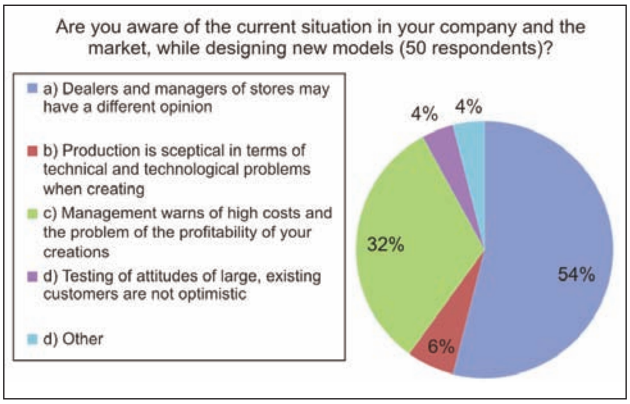

Fig. 8. Terms of designing new models in companies and market

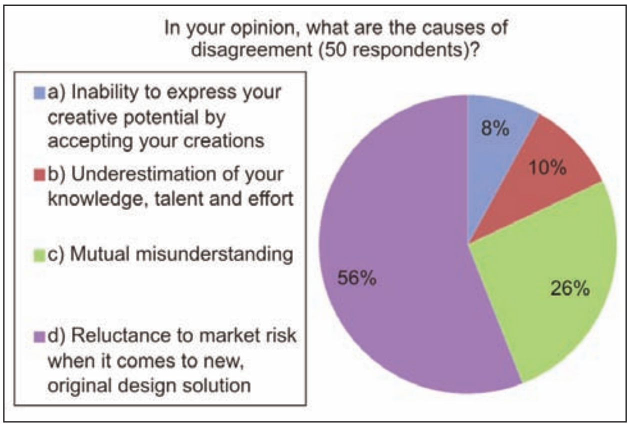

Fig. 7. The causes of disagreement between designers and marketing experts

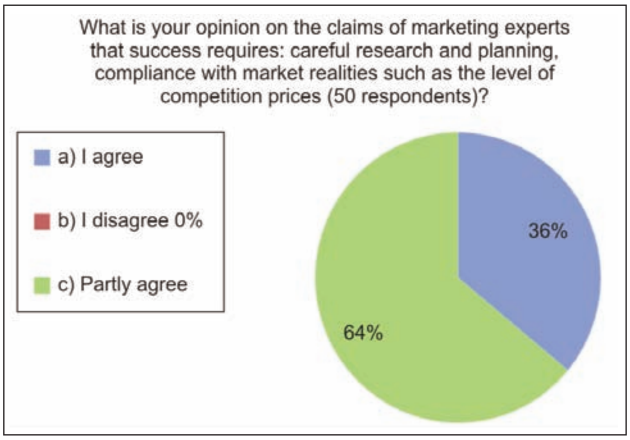

Fig. 9. Claims about requires for success

The question eight referred to the possible existence of awareness of designers on the state in their company and market, when they make decisions on which models will be produced in a series and offered to the market. More than half of respondents, or 54%, think that traders and managers of stores may have a different opinion on their offered models. For the offered answer, that management can warn of high costs and problematic profitability of their creations, opted 32% of respondents. The remaining respondents, or 6%, consider that the cause of rejection of the new models can lie in scepticism of production in terms of technical and technological feasibility of these models. For the answer “Testing of attitudes of large, existing customers are not optimistic” opted only 4% of the respondents (figure 8.).

The question nine referred to the views of designers related to claims of marketing experts that the success on the fashion market requires: careful research, planning, respect for market reality, respect for the competitors and the level of their prices, etc. Almost two thirds of respondents, or 64%, only partially agree with the foregoing, the typical marketing attitude. However, a significant percentage of respondents, or 36%, fully agrees with the views of marketing experts. As it can be seen, most of the designers only partially agree with the statements of marketing experts (figure 9).

The tenth question referred to the views of designers on whether the changes in the educational system of designers (the study of the principles of fashion marketing) and marketing experts (study of design principles) could help in bridging their disagreement. The answers were surprising and encouraging: all 50 designers, therefore 100% of respondents answered affirmatively to the question (figure 10)

The second part of the research was carried out in twenty fashion companies in the Western Balkans. Testing of marketing experts was conducted in the period from October to November 2015. The used technique was the personal-depth interview, which assumes a formal, direct questions and informal conversation. The purpose was to get respondents indicate free views about their disagreements with designers. Direct questions were related to: the role of designers in differentiation of products, the existence of disagreement, the reasons of good cooperation, and misunderstandings with young designers about production material, price, selection of collections for the upcoming season, about the requirements of large customers, the meaning of marketing research, caused by company owners and related to differences in formal education.

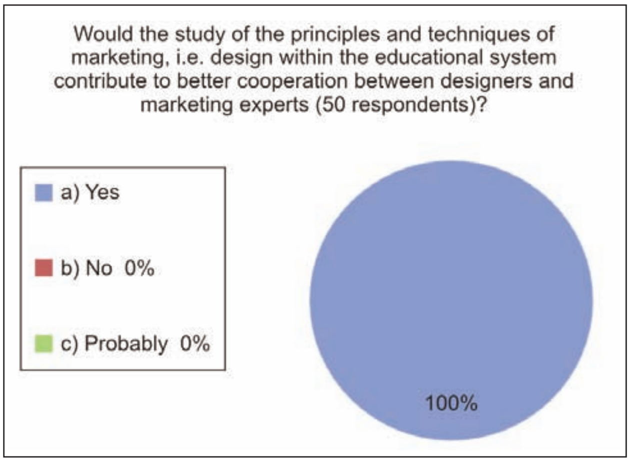

Fig. 10. The agreement on the importance of the principles and techniques of marketing, i.e. design within the educational system in contribution to better cooperation between designers and marketing experts

It has been asked if there is a misunderstanding with the designers with whom they work in their companies, 25% of marketing experts responded negatively. As reasons for the good cooperation and understanding of the experience of designers, their respect for market requirements and specific situations that are told precisely by them have been specified.

The remaining 75% marketing experts draws attention to different (occasional) causes of disagreement with designers. Most complaints (32%) are given to younger designers, because of their pretension or attitude that they need marketing experts only for the promotion of their models and for the offer to customers.

About 23% of respondents state design proposals related to the material for making garments as a reason for misunderstanding. They do not dispute the right of designers in selection of the material, but they point out that the selected material is often too expensive which threatens the planned profitability of these products. In fact, based on the purchasing power of their target customer and the price of similar competing products, they consider that the increase of the final selling price is not possible.

Disagreements are also present at the final evaluation, i.e. selection of models that should be produced in series for next season. 57% of marketing experts think that the applause of the present, selected audience at fashion is not sufficient guarantee for the market acceptance of those models that are carried by mannequins, which is not the designers' opinion.

Misunderstandings occur because of the demands and proposals of the key long-standing customers, those bound to both, the design and assortment of garments. Marketing experts consider that these claims should be accepted, and then, after the market testing, necessary redesigning and selection of assortment, should be carried out.

All interviewed marketing experts believe that designers cannot ignore the results of marketing research as a basis for their creative efforts in the process of fashion designing.

Marketing experts almost completely agree with designers when it comes to excessive interference of companies' owners in their affairs.

Misunderstandings could be reduced if designers acquired more marketing knowledge, and marketing experts learn more about design.

THE CONCEPT OF FASHION MARKETING AS A POSSIBILITY OF REDUCING TENSIONS BETWEEN DESIGNERS AND MARKETING EXPERT

Fashion marketing can be viewed as a business philosophy that deals with current and potential customers of clothing, as well as with products and services that are related to clothing, with the intention to achieve long-term goals of fashion companies [5].

The concept of fashion marketing should include positive aspects of high interest in design, customers and profit, admitting the existence of interdependence between marketing and design.

Tensions between designers and marketing experts can be reduced if designer realize that marketing can improve the creative process, and if marketing experts accept the fact that in fashion industry design may, in addition to compliance with customer requirements, dictate these requirements. Marketing experts may produce a bunch of information on customers' requirements, and analyze the offered illustrations, but cannot develop detailed specifications for design of fashion products. Marketing used in the fashion industry has to respect the role of design [9].

Reducing tensions between designers and marketing experts would help the greater appreciation of postmodern society and its culture. In this sense, designers are increasingly creating products that are not defined by a function, but its identity. At the same time, an equal role in deciding on purchase have both a product and its image, i.e. and public image.

Application of the concept of modern marketing assumes review of curricula according to which designers and marketing experts are traditionally educated. Marketing students must study the process of product design. Design students have to know the key principles of marketing, especially of fashion marketing that affirms their position in fashion companies [9].

The concept of fashion marketing assumes close relationship between marketing strategy and design strategy. It is necessary to harmonize marketing experts and designers for each strategic option individually.

For the success of the concept of modern marketing the crucial thing is integration of marketing and design in the process of development of a new product. By making the use of the product easier and its performance better, designers contribute to the differentiation of products and attracting customers. Marketing experts provide information to designers on the needs of customers, competition and problems in existing products. Working together with marketing experts, designers can generate and visualize ideas that are sent to check. When the idea is visually presented, marketing experts, together with the designers consider the decision and discuss whether it is feasible. In the later stages of product development process, marketing experts test new models and collections before launching them into production. New models must be secured by the designer. Marketing experts have the responsibility of providing information, feedback and recommendations to designers.

One of the complex activities of the fashion marketing is foresight. However, designers and marketing experts need to be aware that some changes in the business environment and activities of competing firms cannot be fully predicted. They both know that the fashion industry is known for its high rate of failure of new products, as well as regular discounts for designed products that could not be sold in the period of the main season.

Failures are partly a reflection of the high risk that characterizes the fashion market. They may also be a result of inadequate application of the concept of fashion marketing. However, practice shows that proper application of fashion marketing reduces uncertainty in the fashion industry and reduces the number of business failures [10].

CONCLUSION

Tensions between designers and marketing experts in choosing the range of garments for the market are certainly the consequence of distinct values in which they believe, shortcomings in their formal education, years of experience, the structure of the fashion market, etc.

There are also the areas in which designers and marketing experts have the undivided attitude about values. Successful designers and marketing experts agree that succeed requires careful preparation and implementation of professional skills, they understand the importance of communication even though they attach greater importance to their visual aspect. They tend to agree on the functional component of garments design.

Conducted research shows some specifics in views of designers of the Western Balkans related to their position in the fashion companies, and even mild tendency toward understanding the point of view of marketing experts. Fashion designers of the Western Balkans bother the owners-managers, who sometimes make all the decisions by themselves, even those concerning which new models will be produced and offered in the market. They expect from marketing experts timely information on fashion trends, customers' reactions to their models, insight into the results of the final sales to end customers, the level of competitive prices, etc. Similarly, marketing experts can help designers in creating a profile of customers at the predetermined target market. They believe that the misunderstandings between the designers and marketing experts can be reduced by better mutual communication, as well as by changes in educational programs in both areas.

The views of marketing experts engaged in fashion companies in the Western Balkans, generally speaking, do not differ from those found in the literature. From the knowledge obtained through the interviews with 20 marketing experts, it can be noted a significant increase of appreciation of the role of the designer. However, they, as well as designers, complain about the non-compliance of risk and misunderstanding of the owners-managers. The main issues on which they disagree with designers include: reduction of marketing only to promotion, lack of appreciation for the results of marketing research, the role of large customers, pretentiousness of young designers, the selection of new models, the selection of materials, lack of sensitivity to costs, etc.

Application of the concept of fashion marketing can greatly reduce misunderstandings between the designers and marketing experts. The concept basically has equal appreciation of design and marketing, creative freedom and market reality, inspiration of designers and calculations of marketing experts. In a word, according to the concept of fashion marketing, designers must take into account the logic of profit, while marketing experts must pay attention to their emotions, which are the basis for that "something" that makes new creations specific.

BIBLIOGRAPHY

[1] Vasiljević, M. *Dizajn – savremeni pogledi*, In: Belgrade, 2005, Novi Dani, pp. 267–268.

[2] Bloch, P. *Product Design and Marketing: Reflections after fifteen years*, In: Journal of Product Innovation Management. 2011, no. 28, pp. 378–380.

[3] De Mozota, B.B. *Design management: Using design to built brand value and corporate innovation,* Allworth Press, New York, 2003, ISBN 1-58115-283-3.

[4] Bohdanovich, J., Clamp, L. *Fashion marketing,* Routladge London and New York, 1995, ISBN 0-415-05939-9.

[5] Gašović, M. *Modni marketing*. Institute of Economic Sciences, Belgrade, 1998, ISBN 86-80315-40-0.

[6] Easey, M. *Fashion marketing*, Blackwell Science, London, 1995, ISBN 0-632-03459-9.

[7] Hsu, Y. *Design innovation and marketing strategy in successful product competition*, In: Journal of Business & Industrial Marketing 26/4 nr. 9, 2011, pp. 223–236.

[8] Gašović, M. *Mogućnosti poboljšanja saradnje između dizajnera i stručnjaka za marketing u modnim poduzećima*, In: Tekstil, vol. 62, no. 3–4, pp. 174–185, Zagreb, 2013.

[9] Kotler, P., Keller, L.K. *Marketing menadžment*, In: XII edition, Data Status, Belgrade, 2006, ISBN 86-7478-013-X.

[10] Petrović, V., Gašović, M. *Modna kolekcija*, ISBN 978-86-7672-257-0, Technical faculty "Mihajlo Pupin", Zrenjanin, 2016.

[11] Best, K. *The Fundamentals of Design Management*, AVA Publishing Sa Lausanne, Switzerland, 2010, ISBN 978-2-940411-07-8.

[12] Beverland, B.M. *Managing the design innovation – Brand Marketing Interface: Resolving the tension between Artistic Creation and Commercial Imperatives*, In: Journal of Product Innovation Management No. 22, 2005, pp. 193–207.

[13] Hsu, Y. *Design innovation and marketing strategy in successful product competition*, In: Journal of Business & Industrial Marketing, vol. 26, no. 42011, pp. 223–236.

[14] Zhang, D., Peng, H., KotabeO, M. *Marketing – Industrial Design in New Product Development: The case of China*, In: Journal of Product Innovation Management, No. 28, 2011, pp. 360–373.

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[1] Negoita, O. D., Purcărea, A. A., Banu, G. S., Ghițuleasa, C. *Criteria for process improvement in the Textile and Clothing sector.* In: Industria Textilă, 2017, vol. 68, issue 3, pp. 238-242

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